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CASE STUDY ON THE DESCRIPTION OF THE IMPLEMENTATION OF SMED IN A VOLKSWAGEN AUTOMOBILE MANUFACTURER'S PRODUCTION CELL

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Abstract

This master’s thesis describes the changeover time reduction, through a design improvement, of a mechanical press, in a Volkswagen automobile manufacturer’s stamping press area. This research results from a case study conducted during a period of 5 months. The design improvement resulted from the application of *Single-Minute Exchange of Die* (SMED) technique, with support from other lean tools (5S and TPM). SMED, as a lean technique, aims to reduce waste by reducing changeover times. The improvement culminated in a reduction of 2 minute in setup times and of distance travelled by the operators. Overall, this thesis’ findings expect to contribute in filling a gap in the literature and posing an example of a successful implementation of SMED for other lean organizations.

Keywords: SMED, automobile industry, setup process, lean manufacturing.

Resumo

Esta tese de mestrado descreve a redução do tempo de troca, através duma melhoria de equipamento, numa prensa mecânica, na área das prensas dum fabricante de automóveis da Volkswagen. Esta pesquisa resulta dum estudo de caso realizado durante 5 meses. A melhoria descrita decorreu da aplicação da técnica *Single-Minute Exchange of Die* (SMED), com suporte de outras ferramentas *lean* (5S e TPM). O SMED visa reduzir o desperdício, através de uma redução dos tempos de *setup*. A melhoria culminou com uma redução de 2 minutos em tempos de *setup* e da distância percorrida pelos operadores. Em geral, os resultados desta tese esperam contribuir para preencher uma lacuna na literatura e dar um exemplo de uma implementação bem-sucedida do SMED para outras organizações.

Palavras-chave: SMED, indústria automóvel, processos de setup, produção lean.

List of acronyms

CLT – Central Limit Theorem

DMAIC – Define, Measure, Analyze, Improve and Control

EC – Emotional Competence

EoD – Exchange of Die

JIT – Just in Time

OEE – Overall Equipment Efficiency

OEM – Original Equipment Manufacturer

NPV – Net Present Value

SME – Small and Medium-sized Enterprises

SMED – Single Minute Exchange of Die

SWCS – Standard Work Combination Sheets

TAP – Tri-axial press

TPM – Total Productive Maintenance

TQM – Total Quality Management

TPS – Toyota Production System

VSM – Value Stream Mapping

VW – Volkswagen

WIP – Work in Progress

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1. Introduction

The following study was conducted in an automobile manufacturer's plant and reports the author's master's project, required to achieve Master's degree in Accounting from ISCTE-IUL University. This chapter presents a description of the problem, the research question, methodology adopted, conditions in which the study was conducted, as well as its frame.

1.1 Problem Stating

Lean is a strategy of continuous improvement, it has to be defined and redefined dynamically according to circumstances (Kumar B.R., Sharma, & Agarwal, 2015), will continue to evolve (Hines, Holweg, & Rich, 2004; Marksberry, Badurdeen, Gregory, & Kreafle, 2010), and which more and more world-class companies from all sectors choose to adopt to improve themselves (Deif, 2012; Thomas, Francis, & Fisher, 2015). In the automotive sector, by force of the current paradigm of globalization, adopting new tools and techniques like lean, which allow greater improvement, are essential to survive and compete in this current market (Alsmadi, Almani, & Khan, 2014; Campos, Cotrim, Galdamez, & Leal, 2016; Costa, Sousa, Bragança, & Alves, 2013; Cristina & Rosa, 2012; Kumar & Abuthakeer, 2012).

This thesis' goal is to describe the implementation of SMED in a very specific environment of a Volkswagen manufacturer production cell (an environment for which lean was conceptualized for in the first place) and offer an insight on the subject to what is been shown as an important gap (Saurin, Marodin, & Duarte Ribeiro, 2011).

Lean, its' tools and techniques (like just-in-time and SMED), are still a very researched topic and makes it very appealing to understand why does the subject keeps deserving so much attention, even after all these years since the concept was introduced in the book *The Machine That Changed the World* (Womack, Jones, & Roos, 1990). Also, the need to study the level of maturity of this system, in lean companies, has risen (Saurin et al., 2011) and taking note of the key for a successful implementation of such a difficult system, where many have failed (Marksberry et al., 2010), will also provide better understanding of the topic (Netland, 2015).

1.2 Research question

Considering the problem statement and thesis objective, the research question is defined as the following:

How setup times and waste were reduced through the implementation of SMED in a Volkswagen automobile manufacturer's production cell?

1.3 Case study methodology justification

Quattrone (2006) defines case study as a "*lacuna, and its investigation becomes a way of constructing this space, knowing that it is not possible to fill it completely*". In a more concrete way, a case study is an empirical investigation of a current subject within a real-life context.

Case studies play a very important role in organizational science by providing a method of producing hypotheses for quantitative studies, generating and testing theories (Patton & Appelbaum, 2003) and also give a chance for the testimony to be heard (Quattrone, 2006). The choice of a case study as a research strategy comes out of the need to cover the contextual features of a phenomenon (Yin, 2003). Even though qualitative data usually is found more frequently in case studies, quantitative data is also found and its use is encouraged, to diversify and increase the quality of the research.

What makes case studies uniquely strong is its ability to deal with a high variety of evidence, such as file search, interviews, questionnaires and observation. Since case studies allow the understanding of complex phenomenon, it presents itself as a good solution to study organizations like businesses. The complexity of business organizations comes from a view of them as an open system which is in constant contact with their environment and, therefore, are easily susceptible to changes (Patton & Appelbaum, 2003). Considering the research question and objectives for this study, the approach that better fits is to "*describe the real-life context in which an intervention as occurred*".

The disadvantage to this research methodology lays in its biggest criticism, which is its validity. Implying they lack rigor, are subjective and yield findings. That is why instead of aiming to replicate the study several times, a case study should seek both generalization (achieved by strongly describing the context with great detail and depth) and focus on the specific case (Patton & Appelbaum, 2003).

1.4 Scope of the Research

The area chosen for research is Stamping. The other areas of the company are the painting, assembly line and body. In stamping's press shop is where die changes occur most frequently and, therefore, is where SMED can be more easily studied.

Regarding the press chosen for the study, it is designated as TAP-5. This press was chosen because, out of the six available presses to conduct a study, it was one of the most recent to benefit from a SMED's improvement initiative (more precisely a design improvement). Because of that, the ability to access and collect information about it presented fewer difficulties than with the other presses.

1.5 Thesis outline

This thesis is divided into five chapters, which contain the following topics:

- **Introduction** – this chapter presents the thesis' problem statement, research question, purposes for the study, its scope and limitations;
- **Literature review** – contains the theoretical and methodological contributions to the topic, as well as the current knowledge and findings about it;
- **Methodology** – reveals the reasons which lead to choosing a case study approach and how it was conducted, as well as its methods;
- **Case study** – presents insights into one of the most important lean tools (SMED) describing its methodology, application and impacts in a very particular context, as well as related lean techniques which complement SMED on a daily basis;
- **Conclusion** – the final chapter presents the research's results, as well as revisiting the research question, and the study's objectives and limitations. To finalize, a set of suggested topics are presented for further investigation.

2. Literature Review

This chapter will group the information on the papers read and analyzed, with the objective of gathering recent thoughts on lean and its tools (with a focus on SMED). The present chapter is divided into four major sub-topics: lean; SMED and other lean tools; SMED methodology; and conclusions.

The aims for each sub-topic are to introduce lean (how it was originated, its principles and how it has evolved), then a set of lean tools are presented (with a focus on SMED and why it is classified as part of lean methodology), after that SMED is described in detail, the literature review's conclusions summarizes the main ideas, and, to conclude, a structural analysis to state of the art papers is presented.

2.1 Lean

Lean philosophy originated in Toyota, as Toyota Production System (TPS), which originally was called the *just-in-time* system. These systems were developed by Eiji Toyoda and his production engineer Taichi Ohno (Alsmadi et al., 2014; Womack et al., 1990).

Quoting part of the first paragraph of the "Problem Stating" section, lean is a strategy of continuous improvement, it has to be defined and redefined dynamically according to circumstances (Kumar B.R. et al., 2015), will continue to evolve (Hines et al., 2004; Marksberry et al., 2010), and which more and more world-class companies from all sectors choose to adopt to improve themselves (Deif, 2012; Thomas et al., 2015).

2.1.1 The Toyota Production System (TPS)

TPS was the origin of lean principles but on a very earlier level. In this system, the entire implementation was the responsibility of an external trainer. The TPS's main objective is to eliminate waste and to achieve this goal, the most used technique is Poka-Yoke (Kumar B.R. et al., 2015). Poka-Yoke is a technique to achieve defects free production, which are caused by machine unreliability during WIP, by using inexpensive means (Karlsson & Åhlström, 1996; Pavnaskary, Gershensony, & Jambekarz, 2003; Shingo, 1989).

TPS was born out of the inefficiencies of the mass production system and the constraints of the Japanese market. It was conceptualized in the form of JIT, Kanban and others. The element that allows a company to go from mass production to lean can be summarized in doing more with less (Alves, Dinis-Carvalho, & Sousa, 2012).

When analyzing this method, the TPS house (figure 1) had great contribution in giving stability and scientific support in implementing a lean system (Kumar B.R. et al., 2015).

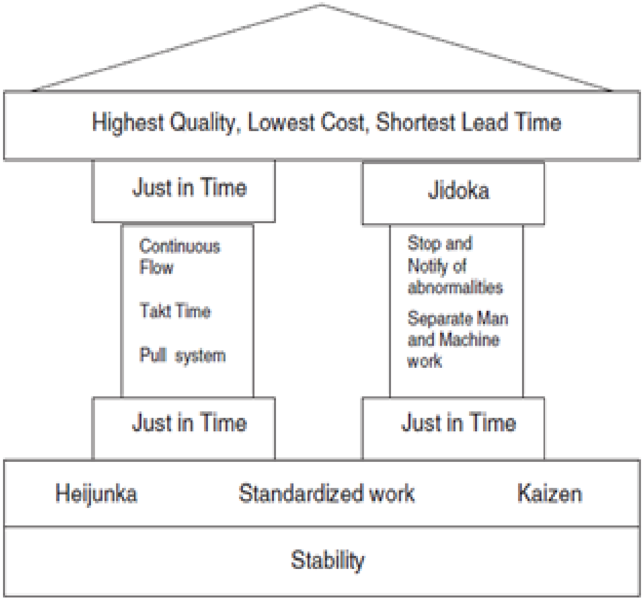

Figure 1 - TPS House (Kumar B.R. et al., 2015)

TPS is often studied as if it were a static model and through an analytic point of view. However, TPS is described by Marksberry *et al.* (2010) as "the current state of a dynamic system that has evolved to that point and will continue to evolve". If we look towards lean and/or TPS as a philosophy that develops over time and requires a high level of commitment, leadership and participation, therefore, one of the elements that should be focused is *jishuken*.

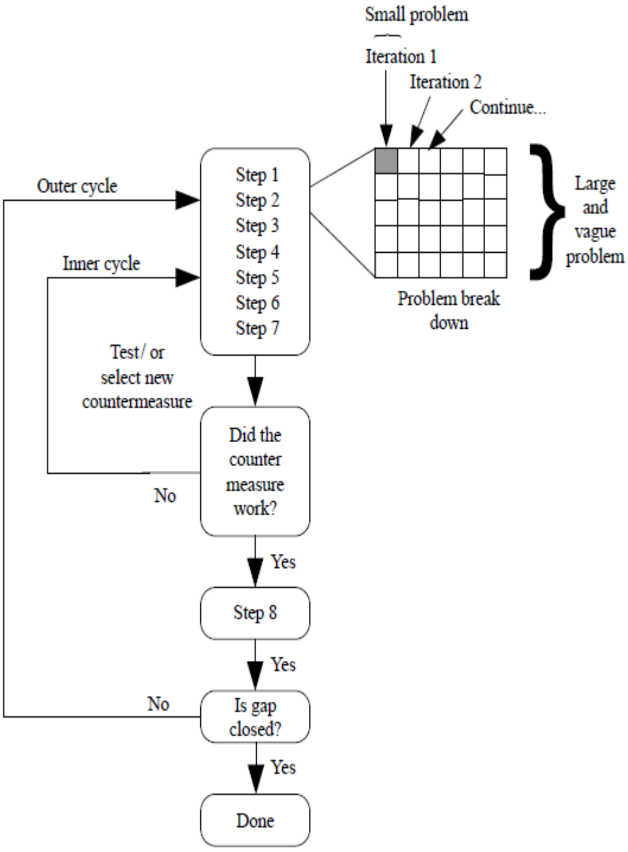

Figure 2 – General work flow pattern for Toyota's eight-step problem-solving process, taken from Marksberry et al. (2010).

Several authors describe *jishuken* as a rapid shop floor activity (like the kaizen blitz model with connections to suppliers to make up for urgent situations).

Jishuken's eight steps (figure 2) break down as the following and have a flow pattern as shown in the figure on the right: (1) clarify the problem; (2) break down the problem; (3) target setting; (4) root cause analysis; (5) develop countermeasures; (6) see countermeasures through; (7) monitor both results and processes; (8) standardize successful processes.

For these steps to be followed correctly it implicates a lot of studying of the problem by the team, and this is the main reason to why *jishuken* can take weeks or months to complete (depending on the problems' nature). It's important to not skip steps in problem solving, because problems that are solved without them have a high probability to return (Marksberry et al., 2010).

2.1.2 The beginning of lean

It all began in 1908 with the model T where Ford's goals and ideas could finally be materialized, which was to have a car with a design directed towards manufacturing which could be driven by anyone.

In 1913 the assembly line was introduced (and later improved) which stopped with the need for workers to move from one place to another since now the work came directly to them (Womack et al., 1990). In practical terms, a line is a group of jobs which produces one product, or a family of products (Pavnaskary et al., 2003). Now, by having workers stay in the same place another problem arose, and this time it concerned communication. Ford created several functions in its factories to face the problem of communication, such as: the repairman; the quality inspector; the housekeeper; and the rework specialist.

When automation reached Ford's factories, these functions gained more importance, since the need for direct-workers decreased. However, the key for the success of Ford's method was in its machines and tools, which could be taught to operate in 5 minutes to an unskilled worker. This made possible huge savings and, by placing the machines in a sequence, increased efficiencies and reduced setup times drastically.

The Toyota Motor Company was founded in 1937 by the Toyoda family. The company was built on the success of the Toyoda family's textile company. In the 1930's the government pressure resulted in changing the business to the motor vehicle industry, firstly trucks and only a couple decades later production turned to passenger cars. To prepare themselves for this new challenge in the auto industry, in 1929 Kiichiro Toyoda (president of what would be named

Toyota Motor Company) visits Ford's factory in Detroit, making it the first encounter between two realities: mass production; and lean thinking. By 1949, the Toyota Company faced a financial crisis, mostly caused by the post-war economic status of Japan, government decisions (which had a direct impact in Toyota) and changes concerning workforce wrights, which resulted in Kiichiro's resigning. His nephew, Eiji Toyoda, continued what his uncle began. Eiji, alongside his production engineer Taichi Ohno, would be the one to introduce lean thinking into the world (Womack et al., 1990).

In the 1950s, Eiji Toyoda visited Ford's plant in Detroit. At the same time, Taichi Ohno was keeping close attention to what was happening in Ford's factories, from which he concluded that the whole process was filled with *muda* (Japanese word for waste) (Dahlgaard Su Mi Dahlgaard-Park, Bhasin, Burcher, Dahlgaard, & Mi Dahlgaard-Park, 2006; Kumar B.R. et al., 2015; Womack et al., 1990). The first adjustments he did to the system were to group workers in teams and assign them a team leader (instead of a foreman). Working in small teams gets the job done with the least effort and highest quality. After everything started to run smoothly, he would meet with the workers to come up with ideas to improve the process (Womack et al., 1990). This process and collaboration is defined by Womack (1990) as *kaizen* (and is detailed in chapter 2.3.5.). Another change was in how defected parts were dealt with. Ohno implemented a system which allowed workers to stop the whole production if a problem was found and it would be fixed immediately, as well as a problem-solving tool called "the five whys". The later consisted in continuously asking why as each layer of the problem was uncovered and then come up with a solution, so it wouldn't happen again. At some time, workers didn't have the need to stop production because everything was running at 100% and with almost no rework being needed (Shingo, 1989; Womack et al., 1990).

2.1.3 Lean characteristics

The lean strategy involves a set of characteristics such as: single piece flow; reduction of inventory levels; save production space and handles costs; and having work processes organized in a cellular based system (Alsmadi et al., 2014). These characteristics are followed by a set of five principles, which are identification of customer value, management of the value stream, developing the capability to flow production, use a pull based method and a continuous pursuit for perfection (Hines et al., 2004). To achieve these principles, it's common to use a variety of tools and techniques like *just-in-time* and *total quality management* (TQM). However the shear implementation of lean tools and techniques don’t make a lean organization (Bendell, 2006).

Regarding the evolution of lean across the system and its implementation, there are four stages identified. The first stage relates to cells and assembly lines, which involves the applications of a set of tools and techniques, such as *kanban*, 5S (housekeeping), *single minute exchanges of dies* (SMED – changeover time reduction) and cellular manufacturing (Alsmadi et al., 2014). Working in cells means to be organized in a group of stations (arranged in an U or O shape) with various jobs and work must flow through the stations (Pavnaskary et al., 2003). The second stage occurs at shop floor level, which involves a great understanding of the organization. Stage three is applying the five key lean principles across the value stream (Hines et al., 2004). Value stream is to include the processes necessary to serve the costumer and add value to the product. This can extend to suppliers and distributers (Alsmadi et al., 2014). Last but not least, the fourth stage is going beyond the rhetoric of customer value and include approaches to the active capture of customer needs (Hines et al., 2004).

About the first stage of lean (the implementation of tools and techniques), research points out that instead of choosing one or two tools/techniques, to successfully implement lean, companies need to implement most (if not all) of the main lean tools available, which are listed as: *kaizen*; cellular manufacturing; *kanban*; single piece flow needs to be in operation; process mapping; SMED; step change/*kaikaku*; supplier development; 5S; total production maintenance (TPM); value and the seven waste (Bhasin & Burcher, 2006).

2.1.4 Value and waste

The primary goal for any company is to make profit. Profit can be obtained and increased in two ways: by increasing revenues; or by reducing costs. Achieving cost reduction is by far a better and more sustainable option than increasing revenues. However, this approach is the most difficult one (Deros, Mohamad, Idris, Rahman, & Ghani, 2011).

The whole purpose of lean production philosophy is to achieve lower costs by eliminating *muda* (Alves et al., 2012; Chen, Lindeke, & Wyrick, 2010; Karlsson & Åhlström, 1996; Womack et al., 1990). It’s about achieving more with less, not by using the assets to its limits but by taking advantage of them the best way possible. This is achieved by doing things better, faster, more effectively and at a lower cost, which doesn’t mean doing things at the ‘lowest’ (Atkinson, 2004).

Waste can be defined by being something that the customer isn't willing to pay and should be eliminated (Alves et al., 2012; Chen et al., 2010; Karlsson & Åhlström, 1996; Womack et al., 1990). There are two forms of classification for waste: necessary waste (*muda type I*); and pure waste (*muda type II*). The first includes all non-adding activities that have to be performed, while pure waste, and the most common one, come from activities that are completely dispensable (Cristina & Rosa, 2012).

Waste can be classified in seven different categories, with them being: overproducing more items than included in the customer orders; inventory, due to increases of finished goods and WIP; motion that doesn't add value to the final product; waiting for any resource throughout the flow of design and production; transportation, or the additional movement which isn't compatible with the product's value creation; over-processing, or additional steps that do not increase the overall value of the product; and not being right the first time or the costs and time associated with repairing and correcting a product (Bhasin & Burcher, 2006; Chen et al., 2010).

The most important kind of waste is inventory, because keeping spare parts doesn't add any value, inventory can hide problems and make difficult the process of solving them. To reduce inventories, machines' down times should be kept at a minimum, batch sizes reduced and production leveling should be practiced (Deif, 2012; Karlsson & Åhlström, 1996). To help this process, there are three key words for storage that managers must keep in mind at all times: where, what and how many (Kumar B.R. et al., 2015).

However, Shingo (1989) advises that eliminating inventories too fast ends up in production stoppings, which delays the whole process of problem-solving. Production leveling, or *heijunka*, is a concept of producing every product, every shift, in quantities equal to demand. To achieve this, the process and sales should be operated at the same time, i.e., at *takt time*. Once again, the solution to achieve takt time is to produce in smaller batches and associate this technique with other lean techniques and tools such as a Kanban based system and a pull method (Deif, 2012).

Apart from the elimination of waste, there is a big focus on value creation. According to Hines (2004), value is created if internal waste is reduced. As the wasteful activities and the associated costs are reduced, the overall value proposition for the customer is increased (Hines et al., 2004).

2.1.5 Implementing lean

Lean production can be divided into four areas of approach: lean development, lean procurement, lean manufacturing, and lean distributors. Lean development and lean procurement are based on a supplier level of involvement.

The first is characterized by developing cross-functional teams, simultaneous engineering, working for integration rather than just co-ordination, developing strategic management and black box engineering. The second looks to understand the suppliers' hierarchies and works with larger subsystems from fewer suppliers.

Lean manufacturing focus on the technical aspects of the lean production philosophy such as elimination of waste, continuous improvement, developing multifunctional teams, developing vertical information systems, decentralizing responsibilities, integrating functions, and letting the customer pull value. Also, the link between lean procurement and lean manufacturing is done by achieving a common goal of a zero defects approach, and implementing lean techniques like JIT to achieve it.

Lean distribution invests on lean safeguards, intensify customer involvement and practice aggressive marketing. When the four areas of lean production are working in perfect sync, the result it's what is called lean enterprise, which focus on thinking global, building a network across the value stream and creating knowledge structures.

Even though there are four different areas to lean production, there are five principles which are applied across them: having multifunctional teams, building vertical information systems, allow no buffers, don't use indirect resources and build networks (Karlsson & Åhlström, 1996).

Normally people who carry out the work have more than 80% of the solutions to manufacturing problems and improvements. Having cross-functional teams creates synergy and a predisposition for solutions which are easier to be embraced by all functions (Atkinson, 2004).

Working in teams is another technique that turned out to be essential in lean production because it enables workers to be more aware of the problems and makes them more comfortable to stop production when needed. This is only possible because of the proximity between workers which enables better communication.

Another characteristic that teams need to have in a cell-based production is multi-functionality, i.e., every member of the team needs to be able to perform all tasks regarding of the process. This allows you to increase flexibility and reduces any production vulnerabilities, such as becoming a lot easier for another member of the team to fill in for an absent worker (Karlsson & Åhlström, 1996).

To achieve this level of efficiency, training is critical, responsibilities must be delegated to workers (giving them more autonomy) and enabling them to make micro-decisions without the need for supervisors (Alves et al., 2012; Karlsson & Åhlström, 1996; Womack et al., 1990).

Even though lean production was originally designed for the auto industry, it has spread, has been applied in other industrial areas such as aerospace, construction and wood products (Kumar B.R. et al., 2015). It has even expanded to various sectors like healthcare, services industries, information technology, office environment and non-profit organization, which serves to show that the lean philosophy isn't exclusive to manufacturing companies (Deif, 2012).

Establishing prices in a lean production company is also an important part of the process. The starting point is establishing the target price. After it is set, the supplier and assembler work together in breaking down the costs, through value engineering techniques, to reach a reasonable profit for both. This system makes it a "market price minus" system instead of the normal system (used in mass-production), where the price is reached by adding the profit to the costs (Shingo, 1989; Womack et al., 1990).

Value analysis is a technique that allows analyzing the costs at each stage of the production and detailing the costs which are critical, with this information it can be achieved further cost reduction. For this technique to maximize its benefits, the supplier must share a substantial part of its information about costs and production processes, always having in mind that he must reach a reasonable profit. This new reality allows Ohno's JIT system to be implemented much smoother. The JIT system is defined by the components being delivered directly from the suppliers to the assembly line at the right time to be incorporated into the production without the need to inspect them, usually several times a day (Womack et al., 1990).

2.1.6 Critics to lean

Ever since its origin in Toyota, lean has evolved as a concept and will continue to do so. If there are critics it means there is room for improvement. Some of the critics made to the method are related to lack of contingency, human aspects, scope and lack of strategic perspective, and coping with variability (Hines et al., 2004).

Implementing lean, successfully, is a difficult task and one that takes a long time to be fully established (Atkinson, 2004; Bhasin & Burcher, 2006). These difficulties can be traced to a lack of direction, planning and adequate project sequencing (Bhasin & Burcher, 2006). However, lean projects shouldn't last very long and its duration should be set at the beginning. This factor is determinant to keep everyone with the necessary motivation to carry out the project. Not having very long term lean projects is also important for demonstrating lean benefits and provide with additional motivation and belief in the system for future projects (Atkinson, 2004).

About uncertainty around manufacturing, it usually concerns the unpredictability in performance and lack of information. This uncertainty can be classified in two types: internal (or endogenous) such as machine breakdowns; and external (or exogenous) such as demand volatility.

Even though lean principles have in consideration the implementation of practices and techniques in environments with a certain level of uncertainty and how to control them or work with them, the reality is that there are a minimal number of uncertainties which are inevitable. To be able to get the system to absorb them, it should be adopted a set of hybrid scaling policies in a dynamic way, which are able to compensate for the internal and external disturbances.

Another way to compensate for the uncertainty and make production run smoother, is to have machines' availability improve, and to compensate for demand fluctuation the lean manufacturing system should work upstream (Deif, 2012).

Regarding the impacts that different countries and cultures have in implementing lean, studies have shown to be contradictory. And, even though it can be against common sense, it is actually harder to implement lean in a smaller factory than it is in a larger one, although the challenges faced in the two cases are different (Netland, 2015).

When managers start to research into lean strategies and methodologies they are somewhat overwhelmed with the amount of information available which functions as a discouragement factor (Atkinson, 2004). This high amount of information and research on the topic is accompanied by a high variety of lean tools and techniques. However, the differences between some of them are only in its name, which increase the difficulty in implementing lean methods (e.g. *value stream mapping* is also called *process mapping*). Poor application of lean tools and techniques caused by this confusion, either by using the wrong tool to solve a problem, using only one tool to solve all the problems or multiple tools to solve only one problem, can increase waste, by spending more time and money, and also contributes to increasing disbelief in the system (Pavnaskary et al., 2003).

According to several authors, there are a few other disadvantages towards lean manufacturing such as possibility of customer dissatisfaction, productivity costs, supply problems, high costs of implementation and lack of acceptance by employees, which leads to a lack of belief in the setup (Kumar B.R. et al., 2015).

Kumar (2015) also highlights that the most important lesson from his study is that after all the work, tools and mindset which has been fully imbed on a person, that person should never be sent back to an unchanged environment, whatever the reason.

2.2 SMED and other lean tools

Starting by revisiting the main idea of the previous chapter, lean is a philosophy which aims to reduce/eliminate waste. Waste can be defined as something that the customer isn't willing to pay, being the seven most common categories overproduction, inventory, unnecessary motions, waiting, transportation, inappropriate processing and defects (Alves et al., 2012; Bhasin & Burcher, 2006; Chen et al., 2010; Karlsson & Åhlström, 1996; Womack et al., 1990).

The following tools were selected based on the relevance of the context and recurrence in the literature review. They are listed as lean tools because of its contribution in reducing waste. Regarding SMED, this chapter will focus on explaining its contribution to lean, whereas the methodology itself will be further described in the next chapter.

2.2.1 SMED as a lean tool

SMED was introduced in lean by being one of the tools used in lean manufacturing, along with *value stream mapping* (VSM), 5S, *total productive maintenance* (TPM) and *six sigma* (Kumar & Abuthakeer, 2012; Ulutas, 2011). The purpose of SMED, and the other tools, is to eliminate waste and improve quality while production times and costs are being reduced. When the need to produce in small batches and high product variation arose, SMED presented a solution to a problem in lean manufacturing, created by the conditions mentioned, which was to reduce the setup times (Kumar & Abuthakeer, 2012).

The contribution of SMED as a lean tool is to enable the reduction of setup times (Costa et al., 2013; Dave & Sohani, 2012). According to Shingo (1985), SMED is based on separating internal setups from external setups. This is achieved by applying a three-staged process:

- Stage 1 – Separate internal setup. from external ones;
- Stage 2 – Convert internal setups into external;
- Stage 3 – Streamline all setup operations.

Studies show that the application of SMED can be translated into a reduction of setup times from 25% to 85%. Setup time is given by shifting the production of one product (or part) to another. Since producing in smaller batches was shown to be the key element to keep up with the demand, making this changeover process as fast and efficient as possible a top priority (Kumar & Abuthakeer, 2012; Moreira, Campos, & Pais, 2011; Ulutas, 2011).

2.2.2 Just-in-Time (JIT)

JIT can be resumed in providing the right part, in the right quantity at the right time (Karlsson & Åhlström, 1996). Several authors confirm in recent studies that JIT is still a current research topic, which may have its reason in a lack of consensus in the literature about what characterizes and defines JIT. Gathering the common points of the authors definitions of JIT, it's considered to be a philosophy and a set of procedures/rules to eliminate waste which can be applied to companies of any type, they also agree that inventories are not desirable and should be eliminated or minimized.

There are seven essential elements which make the foundation of JIT and makes possible to identify its main features: uniform factory load; setup time reduction; machine/work cells; pull system (Kanban); JIT purchasing (which together with the previous four elements make the production flow); product design; process design; supplier quality; workforce flexibility; greater participation and responsibility; continuous improvement; *jidoka*; and multifunction employees.

The benefits of JIT can be listed as the followings: reduction of stock holding costs; reduction of other inventory related costs; improves product quality and production quality; shorter lead times; quicker response to customer and market demands; improvement of inventory turnover; decrease in setup times; increase productivity; profitability; increases manufacturing flexibility; improves competitiveness; enhances communication; eliminates costs with part counting, inspection and quality audits; advantages from the purchase process (Raquel Ribeiro & João Machado, 2014).

2.2.3 Six Sigma

Six sigma is a typically company-wide approach (originated in Motorola) and has been developed by companies such as General Electric (Bendell, 2006). The objective for this method is to eliminate everything that is critical to quality (CTQ), such as causes for mistakes or defects in processes (Antony, 2011; Thomas et al., 2015), by making use of an extensive set of statistical tools and supporting software (Bendell, 2006). This approach has proven to be effective in achieving costs savings and increasing customer's satisfaction, by being based upon project-by-project improvement. However, most of the projects focus more on reducing costs rather than on other features which would increase customer satisfaction, which makes it an incomplete approach. By focusing on cost-down methods it doesn't necessary mean there will be losses in quality. By turning the attention towards control and reduction of variation and waste, cost can be reduced and customer satisfaction increased (Bendell, 2006).

Although lean and *six sigma* have the same basis and origins in Japanese improvement practices (Antony, 2011; Bendell, 2006), lean comes from qualitative models developed from several years of experience and the *six sigma* approach seeks a more critical role in what is happening inside the process steps at that time. Nevertheless, both methods share the same fundamental characteristics: top management commitment; cultural change in organizations; good communication down the hierarchy; new approaches towards production and towards servicing customers; and more training and education of employees. This makes both models compatible, and at some level even complementary. But there are differences between the two approaches. For instance, s*ix sigma* requires more intense training and more investment than lean. *Six sigma* will also eliminate defects but won't address how to optimize process flow. To summarize the differences between the two models, while lean is fundamentally used to tackle process inefficiency issues, *six sigma* is primarily used to tackle process effectiveness issues (Antony, 2011).

The key to successfully implement *six sigma* is to make use of the DMAIC approach, which stands for define, measure, analyze, improve and control (Thomas et al., 2015). This methodology is specially effective for manufacturing and simple transactional processes (Bendell, 2006).

Regarding some of the critics to the *six sigma* approach, many are made towards its complexity of technique and analysis, which are opposites of the ones made to lean (being too simple). Another problem related to *six sigma* is that it presents some difficulties when addressing very complex and profound waste problems. In contrast with this, lean has some difficulties with variation problems and with the control phases, which represent one of the most important features of the DMAIC system (Bendell, 2006).

2.2.4 Total Productive Maintenance (TPM)

TPM is a philosophy introduced by Nippon Denso Co. Ltd. of Japan, a supplier of Toyota Motor Company, in the year 1971, and is set in four principles: no breakdowns; no small stops/slow running; no defects; and no accidents (safe work environment). The referred principles turnaround of what are called the six big losses, which are: breakdowns; setup & adjustment; minor stoppages; reduced operating speed; quality defects & rework; and reduced yield (Almeanazel, 2010).

To achieve these principles, companies are promoted to apply an eight-pillar methodology:

1. Focused improvement;
2. Autonomous maintenance;
3. Planned maintenance;
4. Quality maintenance;
5. TPM in office;
6. Initial flow control;
7. Training and education;
8. Safety health environment.

Considering the principles and pillars of TPM, there are five key features which are characterized by: maximize equipment effectiveness; establish a system of PM for the equipment’s entire life spawn; implementation throughout all company’s departments; involvement of every employee; and emphasis on teamwork.

Out of TPM’s characteristics, the conclusions reached are that the operator is the most important person, because it’s the only one who maintains around the clock contact with the machine, and that TPM won’t solve all problems with a magic touch, because it is a way of being in the company, which needs every department to be involved and is characterized by steady and progressive breakthroughs.

About defects, they originate from the materials, equipment, work methods and people. To minimize them, actions need to take place in choosing materials which don't generate defects, improve equipment, and adopt methods which don't cause defects, as well as educate and train workers to a mindset of autonomous maintenance.

To summarize, TPM focuses on executing six major activities: elimination of six big losses based on project teams organized by the production, maintenance and plant engineering departments; planned maintenance carried out by the maintenance department; autonomous maintenance performed by the production department; preventive engineering executed mainly by the plant engineering department; easy-to-manufacture product design done by the product design department; and education to support the above activities (Jain, Bhatti, & Singh, 2014).

Considering the information given by this tool and its benefits in increasing its rate, it becomes obvious the use of this indicator when the goal is to measure the effectiveness of the implementation of lean tools like TPM or SMED, which aim to increase performance, reduce scrap and defects, reduce changeover times and ultimately reduce waste as a whole.

The cleaning (equipment) concept in TPM context means to eliminate any foreign substance stuck to the equipment or its surroundings. It's not a matter of keeping the factory clean in terms of superficial good appearance, but is to establish basic equipment conditions and to expose hidden defects as a means of attaining zero breakdowns and zero defects (Almeanazel, 2010).

2.2.4.1 Overall Equipment Efficiency

Overall equipment efficiency (OEE) is a way to measure the efficiency of a production plant, by considering all losses and is calculated as:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \ (1)$$

When faced with capacity problems, the first response companies give as a solution is to increase overtime, purchase new equipment or add shifts. However, the answer they should seek is to increase their machines performance, equipment reliability and operator performance, while minimizing idle time. Overall, equipment effectiveness quantifies how well a manufacturing unit performs in comparison to its designed capacity, during production periods.

Availability

Availability considers all events which cause production to stop long enough to justify finding out why it stopped. Availability is calculated as the ratio between Run Time and Planned Production Time:

$$\text{Availability} = \frac{\text{Run Time}}{\text{Planned Production Time}} \; (2)$$

Run Time can be defined as planned production time subtracted from time which production is stopped (whether if it’s a planned or unplanned stop).

$$\text{Run Time} = \text{Planned Production Time} - \text{Stop Time} \; (3)$$

Performance

Performance is a ratio which considers anything that may cause production to be running below its maximum speed, such as slow cycles or small stops. The formula which calculates performance is the following:

$$\text{Performance} = \frac{(\text{Ideal Cycle Time} \times \text{Total Count})}{\text{Run Time}} \; (4)$$

Ideal Cycle Time is the fastest cycle time which a process can achieve in optimal circumstances.

Quality

This ratio considers parts which don’t meet quality standards (reworks included), and it’s calculated the following way:

$$\text{Quality} = \frac{\text{Good Parts}}{\text{Total Parts Produced}} \; (5)$$

Good Parts are all the parts which successfully pass through the manufacturing process the first time without needing any rework (Almeanazel, 2010; Benjamin, Murugaiah, & Marathamuthu, 2013).

Since OEE is a way to measure equipment’s efficiency, the higher it is the better. However, being a relative indicator, when OEE is above 100%, it usually means that the calculations are incorrect or that standards established are set too low.

Improving OEE percentages translates into benefits such as: low machine breakdowns; less idle time; fewer defects; fewer chances of accidents; increase in productivity; decrease in costs (with positive impact on profits); better resources allocation; increase in product quality; and increases motivation (Almeanazel, 2010).

2.2.5 Other Lean Tools

Some lean tools like 5S, *hoshin* planning, mistake proofing, *jidoka*, standardize work, JIT and *kanban* are confirmed to successfully reduce setup times and optimize the process (Bevilacqua, Ciarapica, De Sanctis, Mazzuto, & Paciarotti, 2015; Ulutas, 2011). These tools can be combined with SMED, and more specifically 5S can be used to make SMED more effective (Dave & Sohani, 2012).

2.2.5.1 Kanban

Kanban is a visual control tool which deals with materials requirements planning and re-ordering point, and can therefore determine the amount of WIP. It makes possible to make the process smoother when lot sizes differ between process steps and works to benefit the pull system (Kumar B.R. et al., 2015; Shingo, 1989). Kanban was implemented by Ohno, in Toyota, linking the assembly line directly with the suppliers daily. The aim for this idea is to reduce waste and improve productivity by eliminating inventories, which implicated removing all safety nets (Bevilacqua et al., 2015; Womack et al., 1990). If anything fails, all production stops. Another objective for the *kanban* system was the ability to also function at the buyer's end, i.e., developing a build-to-order system. This allowed Toyota to only produce cars which were already been sold. For this to happen without problems the dealers had to work very close with the factory so timing doesn't fail (Womack et al., 1990).

2.2.5.2 5S

5S was originated by the ideal which a factory should always be working at full capacity, without downtimes, defects or safety problems. To ensure that there are no safety problems it's essential to have good housekeeping and it'll also increase motivation, effectiveness and efficiency.

The 5S stand for *seiri* (organization), *seiton* (tidiness), *seiso* (purity), *seiketsu* (cleanliness) and *shitsuke* (discipline). The 5S can be translated as sort, simplify, sweep, standardize and self-discipline. The first S aims to eliminate any unnecessary movements to search for tools and eliminates possibilities of using wrong tools. This is done by cleaning up the area, creating specific locations for each tool and tagging them. *Seiton* refers to implementing a set of control techniques which enable the desired standards to be met, visual tools are recommended to increase efficiency. *Seiso* is a step created to build, in the workers, habits of maintaining a clean workplace. *Seiketsu* is to create standardized procedures where workers only use the right tools for the right situation, so that the tasks are conducted the best way possible. The final S, *shitsuke*, is to take all the concepts implemented in the previous steps and maintain them on a long-run.

Overall, the 5S can reduce labor hours and rework, eliminate waste, increase safety knowledge and capabilities, health and environmental performances throughout the companies. However, there may be some obstacles with communication which can make implementing 5S a much more difficult task (Becker, 2001). Implementing 5S is critical to any lean initiative, translating into benefits such as: improved safety; essential foundations; sense of ownership and responsibility; waste reduction; improved performance, quality and morale (Kumar B.R. et al., 2015).

2.3 Single Minute Exchange of Dies (SMED)

Companies have been forced to become more flexible, by means of the phenomenon that is globalization, and to match production with clients' requests. This flexibility can be achieved by switching production from large batches, which create several problems such as high WIP and inventories, longer lead times and slower information flows, to smaller batches, which makes possible to change between parts more often. Since producing smaller batches will inevitably result in more setup times, efforts need to be made to reduce them (Bevilacqua et al., 2015; Coble, Trovinger, & Bohn, 2005; Costa et al., 2013; Dave & Sohani, 2012, 2015; Deros et al., 2011; Ferradás & Salonitis, 2013; Karlsson & Åhlström, 1996; R. McIntosh, Owen, Culley, & Mileham, 2007; Ulutas, 2011). Setups exist whenever there's more than one product/part being produced, and, since they take time, are classified as undesirable (Coble et al., 2005).

Idealized by Shigeo Shingo in the early 1950's, SMED is a lean methodology to reduce waste in a manufacturing process (even though the SMED technique could be useful to other areas), with focus in improvement by means of rearranging die change elements into external time and was fully conceptualized in 1969 (Benjamin et al., 2013; Dave & Sohani, 2012; Deros et al., 2011; R. I. McIntosh, Culley, Mileham, & Owen, 2000; Shingo, 1985). McIntosh (2007) defines changeover improvement (also known as setup reduction) by “completing changeover between the manufacture of different products more quickly and to a higher standard”. Changeover is the process of switching the production of one part/product to another in a machine (or series of linked machines) through a process of changing parts, dies, molds or fixtures. Another common term for changeover is setup (Benjamin et al., 2013; Dave & Sohani, 2012, 2015; Ferradás & Salonitis, 2013).

Even though the process spells ‘single minute’, Shingo didn’t mean to use the term in a literal way. The main idea was to achieve changeovers with times limited to a ‘single digit minute’ time frame, i.e., under 10 minutes. It’s this concept of single digit minute changeover time, which determines if a quick changeover is achieved or not (Dave & Sohani, 2012). Ideally, this concept is supposed to evolve into a one-touch changeover and then again to a no-touch changeover, making the changeover time become the absolute minimum (Ulutas, 2011).

SMED projects are divided into four phases: strategic, preparatory, implementation and control. The first phase is where the appropriate strategy is defined, by proposing changeover improvements to the top managers. After the strategy is chosen, goals are set and various planning activities are conducted so that all tasks are organized and deadlines are established. The second phase is where the people who will take part in the project and their roles are distributed. It’s very important that the team is formed by people from different departments, such as maintenance, logistics, engineering and senior management. In this phase, it’s recommended that the team members get training in the methodology and improve communication skills, as well as collecting more data about the activities, with higher accuracy. SMED is applied in the implementation phase. In the control phase, a set of key performance indicators are monitored to ensure that the changeover improvements are sustained over time (Ferradás & Salonitis, 2013).

2.3.1 SMED concepts

Small stops are different from downtime. The first relates to a stoppage time under 5 minutes while the production is running, and is viewed as a part of the process. The latter lasts more than 5 minutes and is held when the production run ends (Benjamin et al., 2013). Downtime can also be planned, like for shift start-ups, production meetings or scheduled maintenances, or unplanned maintenances, such as stoppages for breakdowns or machine adjustments (Dave & Sohani, 2012). Looking at what defines small stops, it is easy to realize how hard it is to reduce or eliminate them. That said, while using the SMED technique small stops are often viewed as acceptable and unavoidable waste, what was earlier defined as *muda type I* (Benjamin et al., 2013).

SMED concept or stage	Assigned SMED improvement technique
Stage 1: Separate internal and external setup	Using a checklist Performing function checks Improving die transportation
Stage 2: Convert internal to external setup	Preparing operating conditions in advance Function standardisation Using intermediary jigs
Stage 3: Streamline all aspects of the setup operation	Improving storage and transportation of dies, etc. Implementing parallel operations Using functional clamps Eliminating adjustments Least common multiple system Mechanisation

Table 1 – Shingo's SMED steps and techniques, adapted from R. McIntosh et al. (2007).

Standardization is also an objective of SMED because it allows to sustain the improvements, provides continuous monitoring of all setups, and reduces (or even eliminates) the need for special skilled workers (Coble et al., 2005; Ferradás & Salonitis, 2013; Ulutas, 2011). Standard Work Combination Sheets (SWCS's) is a tool which can be used for each process to detail each operation, as a way to finalize the standardization of SMED's setup process (Costa et al., 2013).

The *Spaghetti Diagram* is a graphic representation of the movements the operators perform in the assembly lines. Its main objective is to make a documentation of the workers' movements during the shift. For SMED projects, where the focus is setup times, documentation like this is an essential part. It is advised to gather only the necessary information in a handbook with data presented in tables, pictures of parts and drawings of how they are installed (Bevilacqua et al., 2015).

2.3.2 SMED's three conceptual stages

SMED was based on a strong belief of knowing-why, instead of just simply building up know-how. For that reason Shingo proposed following a three steps methodology: separating internal

SMED's Stages Evolution

Stages	Three stages (Shingo, 1989)	Five Stages (Benjamin *et al.*, 2013)	Eight Stages (Deros *et al.*, 2011)
1	Separate internal and external setups;	Differentiate internal from external setups (observe and measure total time losses);	Separate internal from external setup operations;
2	Convert internal to external setups;	Separate the internal elements from the external elements;	Convert internal to external setup;
3	Streamline all aspects of the setup operation.	Make as much internal elements as possible to external;	Standardize function, not shape;
4	-	Streamline internal elements;	Use functional clamps or eliminate fasteners altogether;
5	-	Streamline external elements.	Use intermediate jigs;
6	-	-	Adopt parallel operations;
7	-	-	Eliminate adjustments;
8	-	-	Mechanization.

Table 2 – SMED’s three to eight stages evolution

and external setup; converting internal to external setup; streamlining all aspects of the setup operation (see table 1) (R. I. McIntosh et al., 2000; R. McIntosh et al., 2007; Shingo, 1989; Ulutas, 2011).

Implementing the first step alone is said to reduce changeover times in 30-50%, while converting internal to external setup can result in changeover time reduction of 50% or more and streamlining results in a modest 15% of overall changeover time reduction. These steps often involve activities like machine or process identification for changeover, conducting changeover analysis, training in improvement techniques, team selection and deciding improvement team responsibilities, as it can be seen in the table above (R. I. McIntosh et al., 2000; R. McIntosh et al., 2007).

SMED, as a technique, evolved from its initial concept of three steps, as it is shown in table 2. Currently authors argue that there are five principles, which results from splitting some of Shingo’s three steps approach, dictating how managers should operate this technique (Benjamin et al., 2013), and there are even those who consider the method to have eight steps (Deros et al., 2011).

Applying SMED results in several benefits, obtained by reducing setup times, such as: reduction of stocks, reduction of WIP, reduction of batch sizes and movements, and improvements in quality and production flexibility (Costa et al., 2013; Deros et al., 2011). Besides reducing setup times, SMED’s benefits extend to quick response to customers’ demand, increase in workers’ motivation, improved workers’ safety and health, and parallel operation system (Deros et al., 2011; Kumar & Abuthakeer, 2012). External improvements are a way for the operator to improve his tasks but do not have a direct effect in reducing the setup time (Costa et al., 2013). For this reason, even in situations where SMED isn't being implemented but there is an improvement approach which aims to eliminate waste in current operations, there is a clear manifestation of externalizing die change tasks (R. McIntosh et al., 2007).

Not all tasks need to be made external to achieve changeover time reduction. Another way to achieve this goal is to better allocate the task. Opting for allocating tasks into external time is usually desirable due to under-utilized resources which can be redirected to conduct them. However there can also be benefits to conduct the tasks in parallel or by better compacting them together and reducing 'dead times' (R. McIntosh et al., 2007).

2.3.3 Internal and External Processes

For SMED it is very important to differentiate internal processes from external activities. The main objective for this is to get as much of the next process setup as possible without having the machine to stop its current process (Bevilacqua et al., 2015).

Internal setups differ from external setups in the way that internal setups can only be the one when production is shut down, while external setups can be done while production is running (Coble et al., 2005; Dave & Sohani, 2012, 2015; Kumar & Abuthakeer, 2012; R. McIntosh et al., 2007; Ulutas, 2011).

One approach to find ways to externalize activities is through brainstorming. It allows you to identify and reduce activities which don't add value and, at the same time, to make sure that when the machine is stopped only internal activities are taking place (Bevilacqua et al., 2015).

Although defining internal processes, changeover and external processes is important, there are two concepts which seem to be unexploited, which is the run-up and run-down period. Authors, such as Ferradás (2013), defend that changeover is only finished when production and product quality rates are achieved, i.e. producing a 'good piece'. It's from this concept of good piece that changeover is also called a 'good piece to good piece' process. Having that in mind, the run-up period can be defined as the period between producing the first 'good piece' to the end of the changeover, i.e. the period when production is occurring as well as the interval where production is still being affected by changeover, which can include activities such as adjustments and quality checking. While run-down goes from slowing down production until it’s stopped for internal setup’s exchange of dies process (Ferradás & Salonitis, 2013; R. I. McIntosh et al., 2000; R. McIntosh et al., 2007).

If internal tasks are those conducted while production is stopped and don’t include the run-up, when converted into external there is a need to make adjustments in the run-up to accommodate these changes. Another important feature is that converting a task in the run-up period into external (without altering the content) will have little impact. To sum up, there are a total of three types of tasks: internal, external, and those conducted in the run-up and run-down interval (R. I. McIntosh et al., 2000). The overall process, which considers external, internal, run-down and run-up setups, is called lead time (Bevilacqua et al., 2015; Costa et al., 2013; Dave & Sohani, 2012; Moreira et al., 2011). When addressing long run-periods, where not many of the tasks can be externalized, a focus on separating and converting internal tasks into external won’t have a significant impact (R. I. McIntosh et al., 2000).

2.3.4 Design changes

Other features which need to be considered when implementing SMED is the poor quality of hardware involved in the changeover processes and a considerable extent of unnecessary and unproductivity tasks or which are poorly conducted. These features are related to equipment design and present themselves as great obstacles to the improvement process, and, therefore, need to be rearranged or eliminated (R. I. McIntosh et al., 2000).

Most of the improvement techniques used in SMED, contemplate both organizational and design/technical improvement changes. Design improvements adopt the form of a process or product redesign, new tooling or automation, and have the objective to eliminate waste, inconsistencies and irregularities, bringing benefits in implementing SMED by conducting the current tasks better. They also offer a chance to simplify, speed up or eliminate tasks during changeover. On the other hand, organizational improvements are those who have a direct impact in reducing changeover times, for that reason they should be conducted first and be a more dominant feature when implementing SMED (Deros et al., 2011; R. I. McIntosh et al., 2000; R. McIntosh et al., 2007).

Design changes are inserted into the last stage of SMED, which is *streamlining,* and is reported by McIntosh *et al.* (2000) to have been used by Shingo, after organizational improvements, to enhance changeover performance. Even though it is part of SMED, design improvements don’t always have a direct impact in reducing setup times. For that reason it is important to differentiate design changes which reduce setup times from those which don't, because the ones which don't contribute to reduce setup times are inserted in *kaizen* methodology. This common point between *kaizen* and SMED exists because SMED has its basis in *kaizen* improvement (Deros et al., 2011; R. I. McIntosh et al., 2000; R. McIntosh et al., 2007).

In design changes, it's important to understand that there is no need for large investments. Its impact, on the other hand, needs to be substantial (e.g. by eliminating tasks), and the focus in these improvements shouldn't be forgotten, which is to work with human potential in implementing simple changes that have a high impact (Coble et al., 2005; R. I. McIntosh et al., 2000; R. McIntosh et al., 2007).

2.3.5 Kaizen as the next step

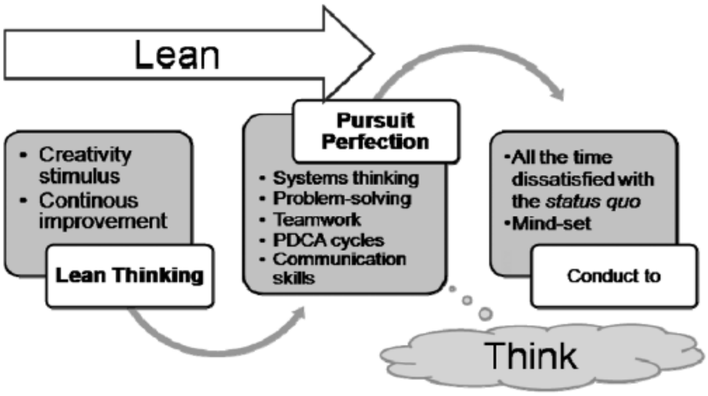

Figure 3 – Lean thinking flow, taken from Alves et al. (2012)

While SMED is a step change improvement approach (R. I. McIntosh et al., 2000), *kaizen* events are characterized by an improvement of both the production and administrative processes, with the objective of maximizing production without increasing costs. It normally assumes that everyone in the company and outside (for instance suppliers) work together in teams. Ideally, kaizen events adopt an approach where any process viewed on the right perspective can be improved. There is also an implicit logic that it's ok to take a step back if improvements are made (Campos et al., 2016).

Continuous improvement implies questioning all processes to identify the problems and find solutions to them. As figure 3 illustrates, it's an important part of the lean thinking philosophy and is also the last step and the hardest one to achieve, i.e., a constant pursuit for perfection. To secure this last step's viability, the previous ones (which involve problem-solving skills, teamwork and communication skills) need to be implemented and running as smooth as possible. Continuous improvement also involves never being satisfied with how things are in the present, i.e., keeping in mind that everything can be improved (Alves et al., 2012).

2.3.6 Critics and limitations to SMED

Even though there is a great effort to implement SMED in companies, some of these efforts are not always successful. Some authors defend that the main reason behind this lack of success is Shingo’s method itself not being an efficient way to reduce changeover times (Ferradás & Salonitis, 2013).

Shingo saw two perspectives into SMED. The first was that to specific SMED concepts there would be matching sets of improvement techniques, and the other was that there was a prescribed sequence according to which the techniques were to be performed. However, earlier research offers a different perspective, it shows that in the early improvement process various and unrelated techniques can be successfully used ‘out-of-sequence’. This means that many of the techniques can have an impact on stages of SMED for which they weren’t design for in the first place (R. I. McIntosh et al., 2000; R. McIntosh et al., 2007). Additionally, applying the methodology as a whole, at a global organizational level, presents more advantages than applying it on a specific situation (R. McIntosh et al., 2007). Another down point to SMED comes from applying the method in a very rigid way. Even though there is a specific technique to achieve a specific improvement, following it blindly may lead to not considering better and more efficient improvement processes (R. I. McIntosh et al., 2000; Ulutas, 2011).

Still related to Shingo’s method, one of the earlier problems with SMED starts with the difficulty to distinguish between its first two steps, which is to separate and convert internal tasks into external (R. I. McIntosh et al., 2000).

Even though the key to master SMED lays on separating and converting internal setups into external setups, some authors argue that there is too much emphasis in the two original first steps of Shingo’s methodology, which might result in achieving more limited results, and highlight the third step of ‘streamlining’. Another effect is that even though externalizing tasks brings improvement, they still need to be completed, which means it doesn’t actually reduce the effort and manpower needed to complete the tasks (R. I. McIntosh et al., 2000).

McIntosh *et al.* (2000) argues that SMED isn’t enough to achieve the necessary improvements. This becomes more obvious when the objective is to reduce/eliminate existing changeover tasks. Improvements of this kind arise when managers start to feel the need for design changes to the existing manufacturing system. By turning the focus from organizational improvements to design improvements, by physically modifying the equipment, companies can achieve better results, with moderate investment, than just focusing on the methodology (Ferradás & Salonitis, 2013).

Another limitation to SMED is how to address task interdependence. This problems usually exist when: there is a need for people to be present during the changeover tasks; space doesn't enable carrying out multiple tasks; there are safety requirements which present some restrictions; tools available are limited; there is insufficient skilled personnel; tasks can only be conducted by a specific person; tasks need to be conducted by multiple operators; there aren't sufficient provisions of jigs or other pre-setting equipment; or when it's required preparation tasks (Ferradás & Salonitis, 2013; R. McIntosh et al., 2007).

2.4 Literature review – conclusions

This chapter aimed at gathering lean and SMED state of art from academic and practical contributions from lean thinking investigation, with the necessary caution of directing it to the scope of the thesis' research. Thus, the present literature review represents the foundations to understand the concepts behind the methodologies used in the study.

The main ideas taken out of this chapter are summarized in the following topics:

- Even though lean is a concept which originated in the mid 1900's (in Toyota with an early designation of Toyota Production System, also known as TPS), it's still used in the current paradigm and has grown and evolved to become one of the most successful production philosophies. Its applications even extended out of manufacturing industries to others such as services, healthcare or construction.
- The main goal for this philosophy is to eliminate waste, which can take the form of seven major categories (overproduction, waiting, transport, inappropriate processing, unnecessary inventory, excess motion and defects).
- To achieve the referred goal, there are several tools, methodology and techniques. SMED is a lean methodology which aims to eliminate waste by reducing setup times.
- Conceptually, SMED is based on the implementation of three stages, which are to separate internal and external setups, convert internal to external setups and streamline all aspects of the setup operation.

Table 3 summarizes the literature review gathered about SMED. Out of the 14 papers analyzed, four are literature reviews and ten are case studies, which represent approximately 29% and 71% respectively.

About the ones which are only of literature reviews, Dave and Sohani (2012) present an overview on SMED in general, while McIntosh, R. *et al.* (2000 and 2007) criticizes the methodology and offers an alternative view. Ferradás and Salonitis (2013) present another approach to SMED, with his tailored method which is designed specifically for an automobile supplier.

Out of the ten case studies referred, only one concerns the automobile industry, two are about assembly lines and four papers are on presses. Taking a look at the objectives placed for the studies, nine are addressed to an implementation of SMED in a specific environment (whether it is a press, an assembly line or a specific piece of machinery). The other case study, conducted by Bevilacqua, M. *et al.* (2015), seeks to understand the significance of quick changeover in a packaging line of a pharmaceutical company. The final common points regarding the studies objectives are between Costa, E. *et al.* (2013) and Ulutas, B. (2011), which aim to achieve standardization for changeover procedures.

Has it was pointed out in the previous paragraph, most of the case studies are based on the implementation of SMED on a specific environment, being only one of them related to the automobile industry. This fact reinforces the importance of this thesis' case study, which offers an insight of the application of a lean technique (SMED), in a mature lean environment, in an industry for which it was originally designed for (the automobile industry). Overall, the benefits taken from this study culminate in making possible a comparison of how the implementation of SMED in the automobile industry has evolved since the times it was conceptualized till its current status.

Authors	Objectives	Literature review	Case study	Company	Section
Costa, E. *et al.* (2013)	1 - Implementation of a methodology to reduce setup times; 2 - Increase of the production flexibility; 3 - Standardization of setup activities.		X	Elevators manufacturer	Presses
Ulutas, B. (2011)	1 - Implementation of SMED methodology; 2 - Prepare an optimal standard procedure for changover.		X	Foam manufacturer	Presses
Kumar and Abuthakeer (2012)	1 - Implementation of SMED; 2 - Description of the setup time reduction.		X	Evaporator (car) manufacturer	Presses
Moreira and Pais (2011)	Implementation of a methodology to reduce setup times.		X	Manufacturing industry	Presses
Dave and Sohani (2012)	Review SMED literature.	X		-	-
Bejamim, S. *et al.* (2013)	Reduce or eliminate the small stop time loss using SMED in a lean manufacturing environment.		X	Metal barrel manufacturer	Barrel production line
Bevilacqua, M. *et al.* (2015)	Uncover the significance of quick changeovers in the packaging line of a pharmaceutical company.		X	Pharmaceutical industry	Assembly line
McIntosh, R. *et al*. (2000)	Prove that the sequencial application of SMED stages nned not always represent an effective improvement route.	X		-	-
McIntosh, R. *et al*. (2007)	1 - Assess retrospective improvement of changeover capability; 2 - Investigate improvement by means of design changes.	X		-	-
Moreira and Garcez (2013)	Provide an insightful case study adressing SMED implementation in a SME processing polyurethane polyether foam.		X	Alpha	Polyurethane foam rolls machine
Ferradás and Salonitis (2013)	Present a tailored methodology for SMED that has been developed specifically for an automotive supplier.	X		-	-
Dave and Sohani (2015)	Setup time reduction on a shaving machine in a gear industry with Kobetsu Kaizen approach and SMED.		X	Gear industry	Shaving machine
Trovinger and Bohn (2005)	1 - Apply SMED methodology; 2 - Implement a developed a sophisticated factory information system, with hand-held wireless barcode computers.		X	Electronics manufacturer	Circuit board assembly line
Deros, B. M. *et al*. (2011)	Improve battery assembly line setup time and at the same time reduce the manufacturing costs.		X	Battery manufacturer	Assembly line

Table 3 – SMED literature review summarization

3. Methodology

The methodology used for this thesis is a case study approach. This approach doesn't seek generalized application. Even though business environments are essentially open systems, case studies are an appropriate tool to analyze phenomenon which can be isolated (Patton & Appelbaum, 2003).

On the following section, it will be possible to understand all the steps followed in building this case study, the reasons which lead to choosing this specific methodology, as well a review on the thesis objectives.

3.1 Descriptive case study

A case study allows a more integrated and full view of a current phenomenon, rather than a fragmented one. Its contribution is based on offering a complete knowledge of a complex phenomenon through a wide variety of evidence, providing a mix of qualitative and quantitative data (even though qualitative methods are more commonly found in case studies) (Patton & Appelbaum, 2003).

Case studies don't primarily seek generalizations because its validity resides in creating hypothesis with intensive and good descriptive language with a focus on the design of the experiment. Contrary to other research methodologies, the hypothesis created aren't supposed to be tested. However, this doesn't mean that case studies should never seek generalization, it means the attention is on the individual case (Patton & Appelbaum, 2003).

Research regarding mature lean environments has been receiving less attention, which can be perceived as a gap in the literature. A case study on the successful implementation of a lean technique (SMED) in the original environment for which it was designed for in the first place, presents itself as an opportunity to expand understanding on the topic (Marksberry et al., 2010; Saurin et al., 2011).

Since research on this specific topic, using this methodology is rather difficult to be found, this case study will focus on describing the process of implementation of SMED in a press and reporting the current situation, making a comparison with the previous one.

3.2 Case study classification and data collection

Yin (2003) acknowledges that there are mainly two major classifications for case studies: single case studies and multiple case studies. The latter is also known as comparative case method, for a better understanding of the difference between them.

This thesis is based on a single case study embedded. This means that the research is of a phenomenon on a specific/unique context and that there are more than one unit of analysis (embedded) which will be studied (Yin, 2003).

Following Patton & Appelbaum (2003) case study methodology, data collection was based on direct observation of events, informal interviews with the participants in the process, the company's data base program and reviewing of documentation. To better understand the die change process and timing times which take to complete each task, video recordings were used, with support from documentation and technical information sheets.

The timeline, in which the study was conducted, is between March and July 2017, which corresponds to the period just after the improvement. For this reason, data collected from the period before the improvement wasn't possible to be visualized directly, as well as the period in which the equipment was being improved. This is one of this research's major limitations and will be taken into an account throughout the study.

3.3 Case study frame and research objectives

The focus of this study is to describe the implementation of a SMED initiative (more specifically a design improvement), how it contributes to reduce waste and at the same time add value from the clients' perspective, by analyzing the impacts from the improvement made.

Regarding the structure of the case study, it will be divided into eight separate parts, which are listed as: introduction of the company, description of the press, description of the production process, description of the improvement, description of current and previous setups, description of the lean tools used to complement SMED and discussion of the results and impacts analysis.

In the introduction, a brief storyline on Volkswagen as a brand and the company is presented. Following the introduction, the press' specifications, the reasons which culminated in the choice of the referred press, and its layout are described. The third part focuses on describing the press' production process, which enables an understanding of where the improvements can be directed. The fourth and fifth parts aims to analyze the core of the study, which are setup description and the improvements made. Before the discussion and final conclusions about the study conducted, it is offered an insight on lean tools and techniques, which complement the implementation of SMED and are used on a daily basis.

Considering the characteristics of this case study and of SMED, there is a set of propositions (P) which were designed to serve as guidelines for the study:

P1 – the implementation of SMED resulted in the reduction of setup times.

It is the fundamental aspect and will act as a foundation for other propositions, as well as the case study itself. It'll also support the theory of SMED as a lean technique which can be successful in reducing waste by reducing setup times.

P2 – through SMED it is possible to reduce setup times to a single digit minute.

This proposition is based on the main goal of SMED, which is not to reduce the changeover times to a *single (one) minute* but to a single digit number of minutes, i.e., under 10 minutes.

P3 – elimination/reduction of non-value adding tasks related to tasks such as materials and equipment misplacement.

Removing inefficiencies of setup operations won't have a big impact in reducing setup times but it will increase its efficiency, making tasks easier for the operators and ultimately contribute to reduce waste.

P4 – increase in the standardization of changeover operations.

As part of the final stage of SMED, the number of standardized tasks will increase which will enable a better work flow, reduce the setup times and waste.

P5 – constant improvement of the changeover process which is part of the final step in implementing SMED.

Verifying that implementing SMED isn't a single action plan on a short time but a continuous intervention on a system, with a mindset on the organization as whole, it is also very important and will provide support for recent findings in the literature.

To better understand the flow of each task and setup, Grant's diagrams are used and will assist in illustrating the progress of different stages of a project. It's a tool which groups several tasks, shows who's responsible to execute it and how long it takes to do it. It allows an evaluation of the costs from consuming resources to complete each task.

3.4 Implementation steps

Following Shingo's (1985) methodology application of SMED, there are three stages to it:

First stage – separate internal setups from external setups;
Second stage – convert internal setups into external setups;
Third stage – streamline all setup operations.

However, practical application of SMED comprehends the implementation of preliminary steps which will create the foundations for its successful implementation. Costa *et al.* (2013) lists a total of nine steps for a complete implementation of SMED:

1. Initial observation – of the whole process and identification of tools and equipment used, as well as movements of the operators;
2. Dialogue with operators – to identify problems regarding the setup process;
3. Video recording – to visualize the movements across the setup process;
4. Construction of a sequence diagram – which will describe the setup operations, its duration and distance travelled by the operators;
5. Construction of a spaghetti diagram – which will illustrate the movements of the operators, highlighting areas of greater affluence;
6. Verify application of the first stage of SMED – separate internal from external setup;
7. Verify application of the second stage of SMED – convert internal to external setup;
8. Verify application of the third stage of SMED – streamline setup operations;
9. Results analysis – and verify the impacts from SMED.

Since the implementation of the referred stages occurred prior to the case study's timeline, it wasn't possible to verify it directly. For that reason, this study will work on the assumption that the first and second stages of SMED were applied. However, data gathered from the company's internal data base and through informal interviews, enabled its verification.

Steps one to five, which represent the preliminary stages of SMED can also be used to eliminate inefficient time caused by poor location of tools and operations, as well as don't having the correct materials and equipment when it's needed to perform the tasks (Ulutas, 2011).

Other lean tools, such as 5S, can be applied in the third stage of SMED. Although it won't make setup times shorter, it will help making tasks easier for the operators and increase overall efficiency (Costa et al., 2013). There are authors who go beyond the described steps and include what would be a tenth step, which would be to constantly improve the process by repeating the previous steps over and over again (Dave & Sohani, 2012; Moreira et al., 2011). An example which illustrates the conceptual stages and practical techniques, as the ones described above, can be visualized in figure 4 (Kumar & Abuthakeer, 2012).

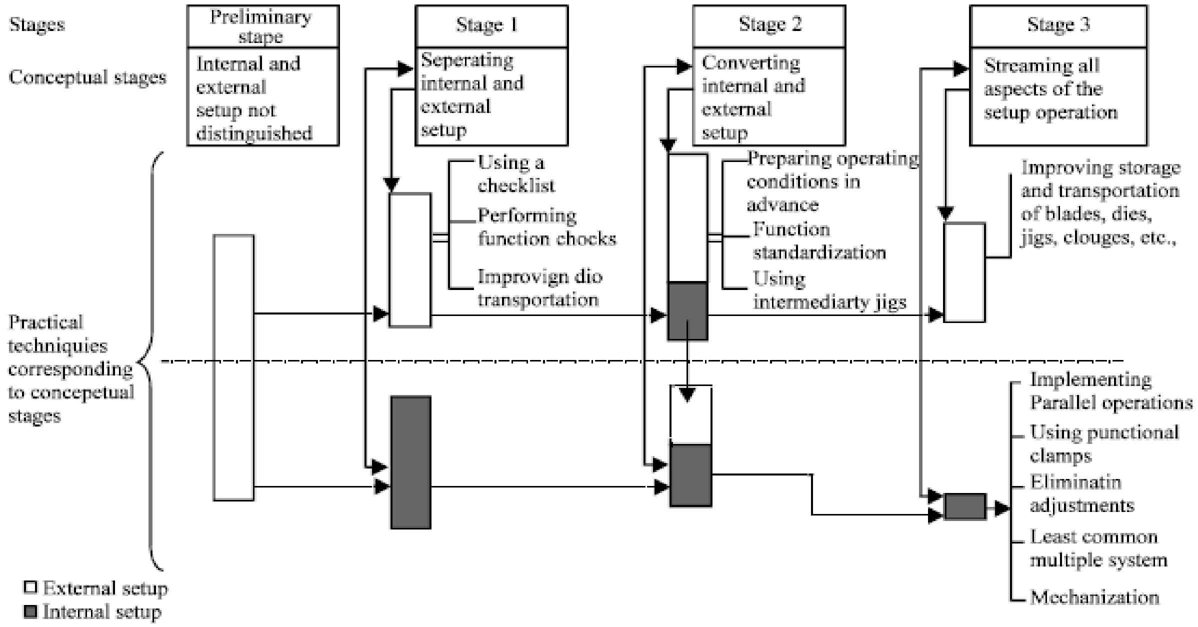

Figure 4 – The conceptual stages and practical techniques of SMED, taken from Kumar B.R. et al. (2015).

Since this case study describes an improvement made by a design change, which is located in the third stage of SMED (R. McIntosh et al., 2007), it won't be possible to verify directly the application of the first two stages (which are to separate and convert internal from external setups). However, considering the information gathered through informal interviews to production's coordinators and team leaders, the study was conducted with the assumption that the first two conceptual stages of SMED were implemented.

4. Case Study

This section provides the field research carried out in a Volkswagen automobile manufacturer. The matters presented have five major subjects, which are a presentation of the company, setups description, design and process improvements accomplished, lean tools associated with SMED and conclusions about the previous subjects. The referred subjects are divided into a total of eight topics.

As it was pointed out in the methodology, the study was conducted between March and July of 2017, which matches with the period just after SMED's design improvement.

The design improvement focused on internal setup's tasks, for that reason, aside from external setups, the remaining setups didn't suffered significant alterations. Therefore, only internal setups will be compared with changeover process before the improvement.

4.1 Volkswagen: the company

Volkswagen or VW (figure 5) is one of the world's leading automobile and commercial vehicles manufacturers and the largest carmaker in Europe. Its origins go back to 1930, in Germany, and its automobile manufacturing project with the name "*Käfer*", also known has Beetle. VW's desire was to create a cheap automobile, affordable by anyone, through a savings system directed to its purchase. Ferdinand Porsche was the engineer responsible for developing the model, even though its design was widely inspired by Hans Ledwinka's cars for Tatra. The current chairman, Mathias Müller, has been in office since 2015.

Figure 5 – Volkswagen logo

The company aspires to be a role model of competence and innovation for the Volkswagen brand and its mission is to produce high quality automobiles, by developing human resources' competences orientated towards innovation and set on value creation, flexibility and social responsibility principles. The company aims to achieve maximum productivity, maintaining top quality, client satisfaction and qualification, workers well-being and motivation.

Environmental responsibility is guaranteed in all of the company's angles aiming at production and product sustainability, through continuous improvement of environmental performance inside the plant and near the community. Volkswagen Autoeuropa values its geographic location as a competitive factor and closing gap to new global markets.

Figure 6 – Company's compound

4.2 Stamping press

The *press shop* area has a total of 38.933 m^2, a maximum height of 16.5 meters and accommodates six presses, which are responsible for supplying parts to the body shop (working as an internal supplier) and are used to make up to 467 cars per day. Parts made in the presses are the core materials to make cars and, therefore, the overall car production is dependent on good performance from the press shop. The case study's target is a tri-axial 32.000 kN press (TAP), designated as TAP-5 and its specifications (figure 7) are the following:

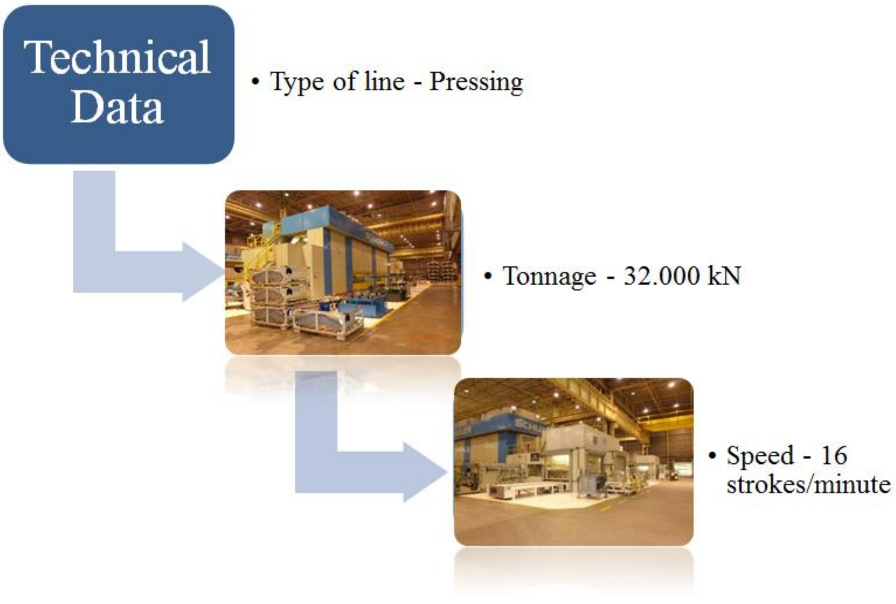

Figure 7 – TAP-5 technical data and pictures

It’s a tri-axial press because it uses a transfer (figure 8), which makes 360º back and forward motions, making it capable of transferring parts from one operation to the next. The press supports up to six operations, i.e., each part can be processed through a maximum of six different dies (see figure 9 for an example of die sets). However, it’s not necessary for all stations, of each operation, to have a die in it.

Figure 8 – Transfer

In the Press Shop, there is a total of 28 die sets in use for TAP-5. There can be operations which are empty, other than operation 079, which is always an idle station (see topic nº 11 of figure 10).

The press has two rams (punctures) which are responsible for exerting the necessary force to shape, cut or bend the blanks. For each ram there is a corresponding table, which can take up to three dies each. The other four major components of the press are the feeder, Robots 1, 2 & Z (see robots’ positioning in the layout on the next page), the washer/lubricator and the convoyer belt (press’ layout on figure 10).

Figure 9 – Die sets

Currently the press is operated by three teams, in three shifts of eight hours a day, totalizing 18 shifts per week. The teams are composed of one team leader, two line leaders and five operators.

The press’ uptime translates into 87%, being the remaining 13% downtime related to meetings, meals, maintenance, breakdowns and repairs. Per shift, a total of 4.360 strokes are targeted, and the targeted strokes per hour are of 600. One stroke is able to produce up to four parts. For that reason, the unit for comparison is the stroke.

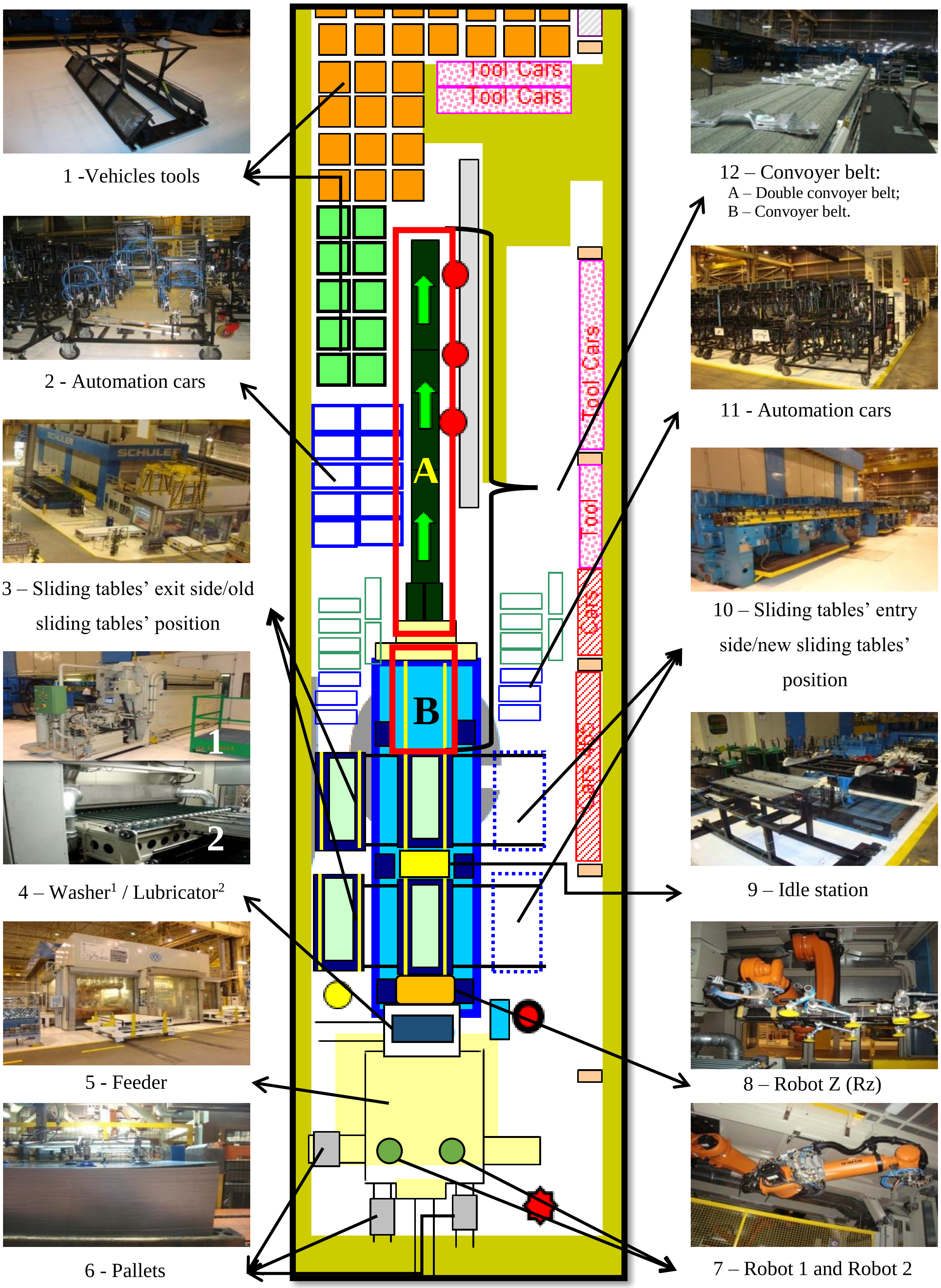

Figure 10 – Press layout

4.3 Production process

The process described below focuses on the production of vehicles' parts by the press. Globally, it can be divided into seven stages, since the raw material (steel coil) is consumed, till its storing:

Figure 11 – Steel coil's warehouse

1) Steel coils (figure 11) are placed in a coil machine which unrolls, straightens and cuts them to form blanks (steel plates) with strait shapes and specific measures. For the same process, there is another cutting machine, with a ram, which uses a die to make rounded shapes and inside cuts (operating similar to a press). This is considered to be the first operation and has the designation of operation 010.
2) Blanks are then piled on a pallet, stored and placed on hold to be assigned to the press which will produce the corresponding part.
3) At the press, blanks are placed in the feeder, which separates them through a magnetic process, does a final quality check through sensors and sends it to the washer (if it's an exterior part) or the lubricator (if it's an interior part).
4) The following operation is the most important one (operation 020). In it the blank is positioned on the first table and the puncture of the first die (located on the bottom half) applies force, pushing the cushion to give what will already be the final shape of the part.
5) The remaining operations go from 030 to 070 and are responsible for making the necessary cuts, holes, bends, shapes and calibrations.
6) Between the two tables there is an idle station which secures the passing of the part from one table to the other.
7) At the end of the line, the part exits through a convoyer and is submitted to a quality check before being stored in a rack.

4.4 Improvement process

Major improvements made to the presses or processes often mean investments of a considerable amount. Improvements of this nature are labeled as design improvements. For that reason, improvements are planned, forecasted and executed by a team composed of company's workers alongside the press' and/or equipment's OEM, to ensure that the improvement is implemented the best and most efficient way possible.

Other improvements in a smaller scale are assessed and managed by a specific department with the designation of GTI. These improvements are categorized in two ways, those which lead to effective savings and those which don't. This allows improvements that only contribute to an increase in efficiency to be acknowledged and rewarded.

4.4.1 Design improvement TAP-5

The design improvement made to TAP-5 began in November 2015 and ended in February 2016. The list of improvements implemented in the press concerned an entirely new feeder and updating setup processes to the latest safety standards.

These improvements created the necessity of rearranging changeover tasks. The difference between internal setups, before and after the design improvement, can be visualized in chapter 4.6 and its sub-chapters. The new internal setups contemplated less manual tasks and enabled a better organization of manual and automatic tasks. On the other hand, the new feeder implicated a new set of die change tasks, more specifically internal setup operation 4, described in table 6 (from sub-chapter 4.6.2). All of the improvements mentioned enabled setup times reduction and also increase parts production.

4.5 Exchange of dies

The die change process can be simply described as the process of changing production from one product (or part) to another. In the current study a die change occurs when production changes from one part to another, and follows the sequence described in the paragraphs below.

The process begins with the execution of several preparation tasks such as preparing pallets, loading orders or verifying if the cushion's pins are down. When the production of current order is reaching its end, the line leader signals the team and starts slowing down production. After the last rack is filled and the line is emptied, die change (internal) setup is initiated.

The die change setup has two different sets of operations: manual tasks; and automatic tasks. Manual tasks are the ones executed by the operators and line leaders, and are divided into two major operations: change grippers and idle station's jigs; and exchange Robot Z's (Rz) automations. Automatic tasks are those which are executed automatically by the press.

About the referred setup, after it is initiated, sliding tables come out from the exit side (see figure 10 of press' layout, item nº 4). Then, the operators can go inside the press, perform the exchange of Rz's automations and idle station jigs, making everything ready for the new sliding tables to enter. To finalize the setup, a combination of adjustments to speed, pressure, ramps, elevators and so on, are made to start producing the new order.

Average number of dies change is currently at two per shift, but is expected to be on average three per shift. Sometimes, there is the need to produce parts in larger batches, which means there are shifts where a die change doesn't take place and the only thing there is to do is making sure that production runs smoothly. The setups, considered for the die change studied, only include tasks which are regular, i.e., cyclical or repetitive.

However there can be other tasks which take part of the die change process, but because of not having the characteristics described they weren't considered. The washer or the lubricator is a separate case, because the exchange of this equipment only occurs when production switches between an exterior part to an interior one, or the opposite. For that reason, even though it's one of the press' major components, it's not relevant for the exchange since it's conditioned by the parts changing from interior to exterior or exterior to interior.

4.5.1 Setups

Has it's been indicated in the literature review, die change is a process which comprehends two big setups: internal setups; and external setups. However there are two more setups which are worth analyzing when focusing changeover times, i.e., the time between slowing down production to finish the previous order (before changing dies) and the time when it starts new order production (figure 12).

The other two setups referred are the run-down and run-up setups. The first one concerns the time in which production slows down and the number of parts produced to complete the previous order is meeting its end, as well as completing other related tasks. Run-up setup refers to the time it takes between placing new dies in position and production of new order is being tested, and the time which necessary adjustments are being made, as well as executing associated tasks.

Figure 12 – Die change setups

Currently, setup times and its sequence are as it is shown in table 4 and visualized in diagram 1. External tasks are divided into two setups: one is executed before run-down setup; and the other after run-up setup. Changeover process begins with the first external setups. Then run-down tasks are executed, followed by internal and run-up setups. After run-up setup is executed, the press starts producing a new order, leaving only the second external tasks to be completed.

The first external setup aims to execute tasks which enables everything to be in place to begin the die change, and goes from loading pallets’ stacks to verifying team members positioning. Regarding the second external setups, it is executed as soon as possible, which means tasks such as removing bolts, unplugging cables, taking off gripers from dies on the old sliding tables or storing materials, are executed at the same time as internal tasks. Adding up both sets of external setups, it takes up to 94.500 minutes to complete them. Since the design improvement focused entirely on internal setups, external setups won’t be analyzed in further depth.

Shifting the attention towards changeover time, it takes approximately 25 minutes to be completed, since slowing down production of the previous order till production of new order is stabilized (table 4 and diagram 1).

Setups (Current)

Setups	Start	Finish	Time
External I	-19,000	0,000	19,000
Run-Down	0,000	6,500	6,500
Internal	3,000	18,744	15,744
Run-Up	18,744	25,244	6,500
External II	13,343	88,843	75,500
Total			**25,244**

Table 4 – List of press' die change setups and times

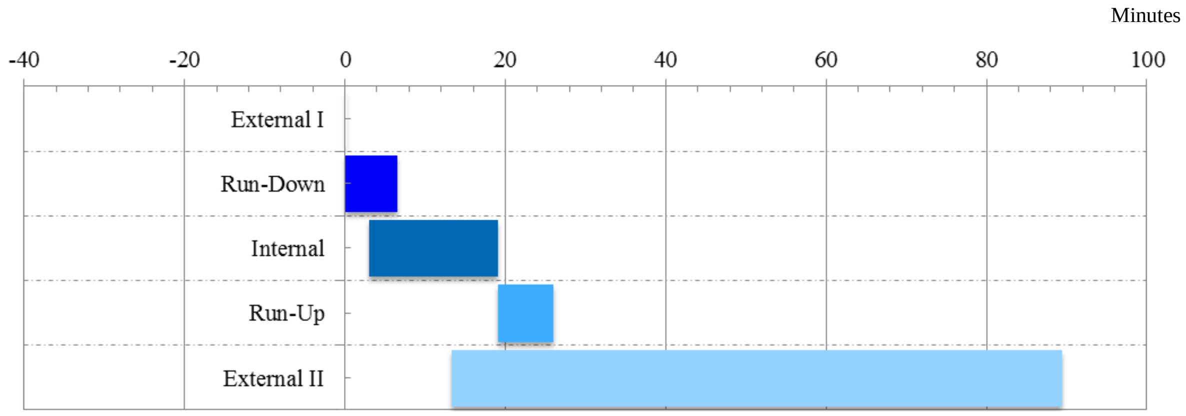

Diagram 1 – Exchange of dies setups' sequence and times

As it was referred, run-down setup involves executing tasks in the time which production slows down and number of parts produced to complete the previous order is meeting its end (as well as completing other related tasks). More specifically, tasks executed in the run-down setup are the following: empty line; make sure that the last rack is filled; register scrap; finish press II inputs; and register reworks. The time it takes to execute the run-down setup is 6,500 minutes.

Run-up setup refers to the time it takes between new dies are placed, and production of the new order is tested, till the necessary adjustments are finished, as well as executing associated tasks. Tasks executed in this setup are: adjust pressure; perform final adjustments to ramps, elevators, etc.; open press II inputs; and verify in progress working orders. Time taken to execute the run-down setup is 6,500 minutes.

For the same reason as external setups, run-up and run-down setups won't be analyzed in further depth.

4.6 Internal setups

Returning to the literature review, internal setups are those which can only be executed when production is stopped, whereas external setups can be executed while production is running (Coble et al., 2005; Dave & Sohani, 2012, 2015; Kumar & Abuthakeer, 2012; R. McIntosh et al., 2007; Ulutas, 2011). The following sub-topics will explain the current setups and the ones before the design improvement made to the press.

4.6.1 Before design improvement

As it was pointed out in chapter 3 and in the beginning of chapter 4, data gathered and presented related to the period during and before the improvement was not possible to be gathered or confirmed directly. Therefore, it is based on the information available in the company's internal data base and by informal interviews.

Table 5 (with visual assistance of diagram 2) summarizes the list of tasks which needed to be executed to complete internal setups of a die change before the design improvement had taken place. It also groups tasks listed in annex II into six sets of internal setups. The characteristic which enabled the grouping of tasks is its sequence (if the tasks were executed one after the other or in parallel).

The first set of tasks (internal setup 1) was executed in part manually by an operator and automatically by the press. While an operator went to get an empty gripper car, the press began to unlock the die and open doors. Standard time to execute this set of tasks was of 1,329 minutes.

The second set of tasks (internal setup 2) was also executed in part manually by four operators and automatically by the press. In this setup, operators unlocked grippers from old production and would get new ones to the transfer. After that, the press closed doors and moved the transfer before opening them again. Time taken to execute this set of tasks was of 2,548 minutes.

The next set of tasks (internal setup 3) was also executed in part manually by four operators and automatically by the press. In this setup the operators continued to unlock grippers from old production and the sliding tables would exit the press. The time which took to execute this set of tasks was of 2,823 minutes.

Internal setup 4 was executed in its majority by the press, with one of the tasks being executed by two operators. The focus in this task was to perform the exchange of idle station's jigs. Time to execute this set of tasks was of 4,953 minutes.

The fifth set of tasks (internal setup 5) was executed manually by two operators and its goal is to complete the exchange of old production’s grippers. Standard time to execute this set of tasks was of 8,257 minutes.

Internal Setups (Before Retrofit)						
Setup operations	**Description**	**Initial task**	**Final task**	**Times***		
				Start	**Finish**	**Duration**
1	Begining of die change	Get empty gripper car to press table	Opening doors	0,000	1,329	1,329
2	Exchange of middle grippers I	Unlock grippers	Opening doors	1,329	3,877	2,548
3	Exchange of middle grippers II	Unlock grippers	Tables with old dies exit and opening doors on entry side	3,877	6,700	2,823
4	Exchange of empty station supports	Opening doors and exchange of middle gripers	Activate warning signals on entry side (lights and sound)	6,700	11,653	4,953
5	Remove old production grippers and supports	Get crane control and pin card	Remove grippers from back transfer to 2nd platen and to automation car	11,653	19,910	8,257
6	Final adjustments	Unscrew table screws and close scrap ramps	Remove electrical cables and pressure hoses	19,640	22,290	2,650

* the times are displayed in minutes

Table 5 – Internal setup operations and times before design

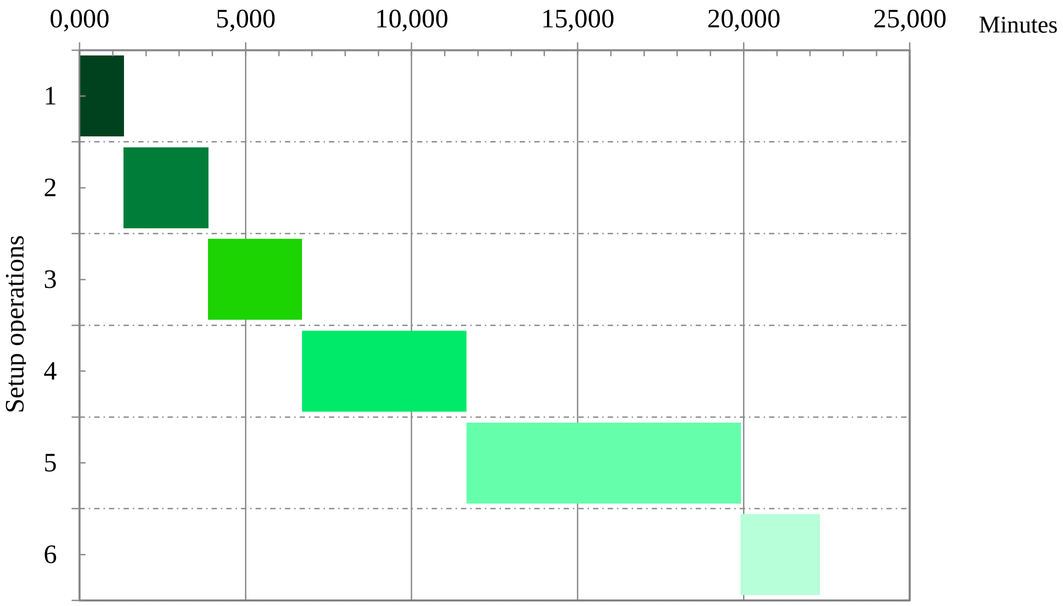

Diagram 2 – Internal setup operations and times after design improvement

The final internal setup was executed manually by an operator and consisted in executing final adjustments of the die change, such as closing scrap ramps or removing cables. The time which took to execute this set of tasks is of 2,380 minutes. Since the empty gripper car was placed next to the press till it was ready to start production, internal setup took up to 22,290 minutes to be completed.

Figure 13 summarizes the line leader and operators' movements when performing the die change before the design improvement. The operators were responsible for performing the exchange of the middle stations' grippers and idle station's jigs. Meanwhile, the line leader placed the feeder and press in die change mode, changed the feeder's automations, inserted the pallet into the feeder, before starting production. The distance travlled by the operators and line leader was of 105m.

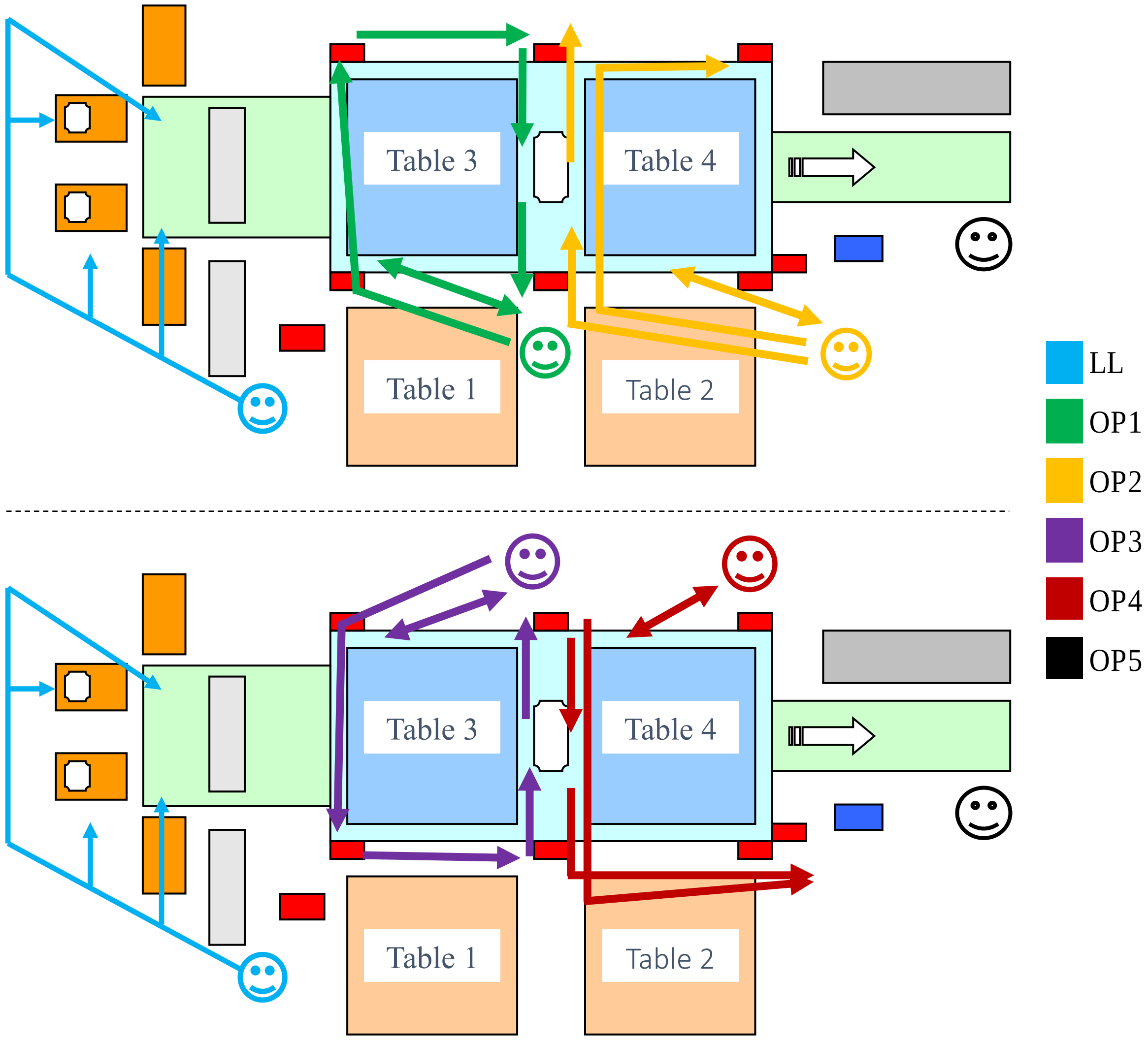

Figure 13 – Die change's manual setups spaghetti diagram (before design improvement)

4.6.2 Current setups

Table 6 summarizes the list of tasks which need to be executed to complete internal setups of a die change after the design improvement had taken place, and diagram 3 helps to visualize the sequence and time length for each setup. The table group's tasks listed in annex I into seven sets of internal setups. The characteristics which enabled the grouping of tasks are type of setup (if it's an automatic setup, executed by the press, or if it's a manual setup, executed by a line leader or an operator) and sequence (if tasks are executed one after the other or in parallel). The diagrams were put together with information gathered by direct observation, with information available from the production department and gathered by conducting informal interviews.

The first set of tasks (internal setup operation 0) is executed by the line leader and aims to complete the necessary tasks to initiate the Exchange of Die (EoD). Time to execute this set of tasks is of 1,132 minutes.

The second set of tasks (internal setup operation 1) is executed automatically by the press. The objective of this set is to make the necessary adjustments and releases, so that the sliding tables inside the press can come out. Standard time to execute this set of tasks is of 1,122 minutes.

The next set of tasks (internal setup operation 2) is executed manually by the operators. It is used to perform the exchange of the middle stations' grippers. Time to execute this set of tasks is of 2,383 minutes.

The fourth set of tasks (internal setup operation 3) is executed automatically by the press, which aims to complete the final adjustments and exit of the interior sliding tables (old). Standard time to execute this set of tasks is of 3,573 minutes.

Internal setup operation 4 is executed by the two line leaders and two operators. This set of tasks consists in changing Rz's automations. Since, to make the exchange, the robot needs to get out of its action radius, one of the line leaders has to control it manually, while the other line leader and two operators change the automations. The time it takes to execute this set of tasks is of 2,573 minutes.

The next set of tasks (internal operation 5) is executed manually by the operators. The objective of these tasks is to complete the exchange of the idle stations' jigs. Standard time to execute this set of tasks is of 2,383 minutes.

The seventh set of tasks (internal operation 6) is performed automatically by the press and focus on executing the entrance of new sliding tables and necessary adjustments to it. Time to execute this set of tasks is of 4,385 minutes.

The final set of tasks (internal operation 7) is divided into three main tasks, which are to move the convoyer belt (A), completing the exchange of the feeder (B) and perform the necessary final adjustments (C). The tasks listed as A and C are executed automatically by the press with the end of the feeder's exchange being set by the line leader, while the moving of the convoyer belt to the correct position in executed by an operator. Time taken to execute these sets of tasks is, of 1,000 minute for A, 7,910 minutes for B and 0,016 minutes for C.

Since the feeder is placed in die change mode till the press is ready to start production, the internal setup takes up to 15,744 minutes to be completed.

Internal Setups (Current)

Setup operations	Description	Initial task	Final task	Times*		
				Start	Finish	Duration
0	Preparation tasks	Empty line	Initiate press exchange of dies mode	0,000	1,132	1,132
1	Begining of die change	Initiate exchange of dies mode	Opening doors from exit side	1,132	2,254	1,122
2	Exchange of middle grippers	Opening doors and operators positioned in middle station	Activate warning signals on exit side (lights and sound)	2,254	4,637	2,383
3	Automatic press operations I	Active warning signals on exit side (lights and sound)	Tables with old dies exit and opening doors on entry side	4,387	7,960	3,573
4	Exchange of Robot Z	Opening Robot Z doors by LL2	Closing Robot Z door by LL2	7,960	10,533	2,573
5	Exchange of empty station supports	Opening doors and exchange of middle gripers ends	Activate warning signals on entry side (lights and sound)	7,960	10,343	2,383
6	Automatic press operations II	Opening doors on entry side and new tables enter	Transfer coupling and adjustments	10,343	14,728	4,385
7	Final operations:	Move exit mat to production position	End exchange of dies mode and initiate production mode			
A	Move exit mat			A) 14,728	15,728	1,000
B	Feeder exchange of dies			B) 0,050	7,960	7,910
C	Final adjustments			C) 15,728	15,744	0,016

* the times are displayed in minutes

Table 6 – Internal setup operations and times after retrofit

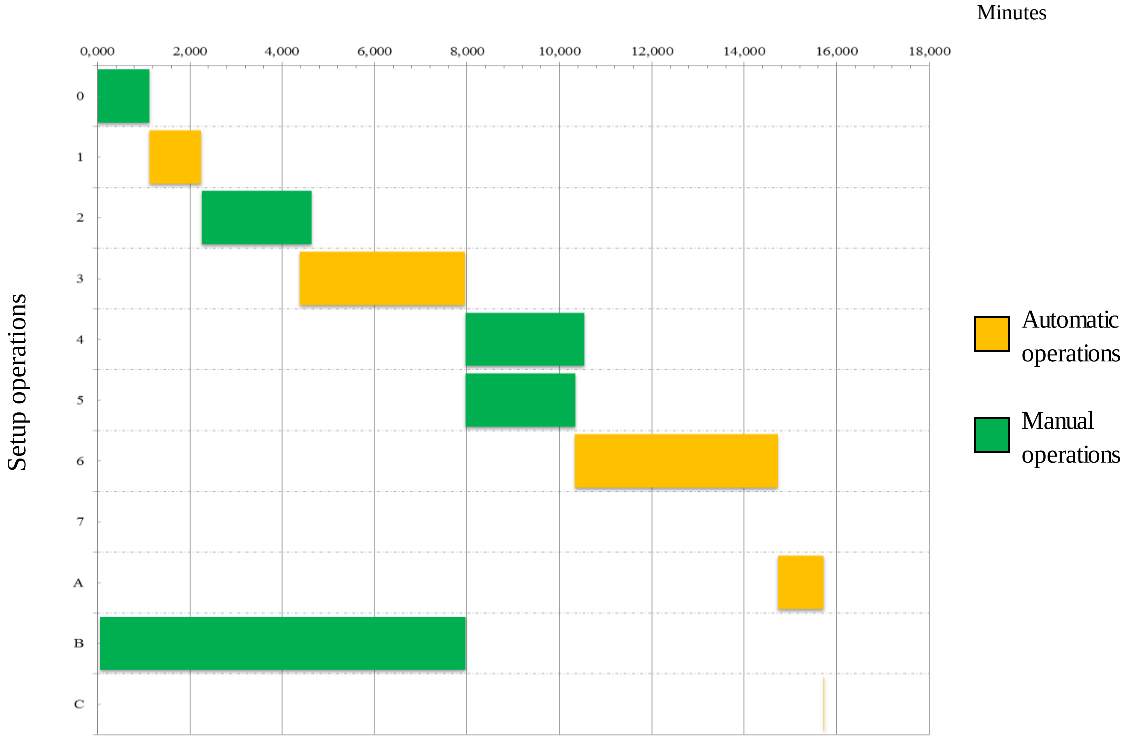

Diagram 3 – Internal setup operations and times after retrofit

Figure 14 illustrates the manual tasks described before with the movements made by the operators, through a spaghetti diagram. To summarize, there are three major tasks which are executed manually: change Rz’s automations; change middle station’s grippers; and change idle station’s jigs. The distance travelled by the operators and line leaders is of 91m.

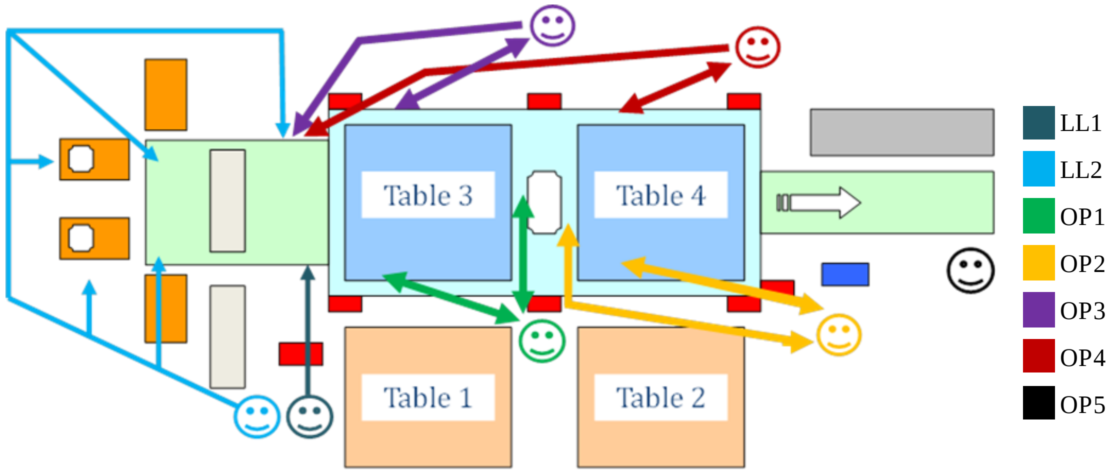

Figure 14 – Die change’s manual setups spaghetti diagram (current)

The construction of this diagram enables a visualization of which tasks can be improved by SMED’s three stage methodology, since the automatic internal tasks are executed by the press and its improvement will often be of a design improvement, instead of an organizational improvement.

4.7 Lean tools

Out of the lean tools and techniques mentioned in the literature review, the ones which are more relevant and used on a daily basis are TPM and 5S's. Overall, these tools build the necessary foundations for a successful implementation of SMED and complement it (when it comes to sustaining it on a long-run).

4.7.1 TPM

TPM tasks at the press are executed on a daily or weekly basis, planned and designed to act as a preventive action. These tasks are divided into two major groups: cleaning and inspection; and lubrication. The press' components, which are targeted by TPM, are: the feeder; rams; convoyer belt (which is divided into two sections, the convoyer belt and double convoyer belt – see figure 10 for press layout, 14A and 14B); idle station; crown; sliding tables and basement. Each operator is assigned a component and is responsible for following its standards. When an anomaly is found, the way to proceed is the following: if it's easy to repair, then it's done by the operators at the moment; if the problem is of difficult resolution, a work order is opened so that it is scheduled a repair by the maintenance personnel. The materials used, to perform TPM tasks, are detergent, oiler, brushes, wrenches and cloths. The tasks whose information was made available are listed on tables 7 and 8.

TPM	
Equipment	**Lubrication tasks**
Feeder	-
Rams	Brush paste on supports' stems (this task is only performed on the first ram)
Convoyer Belt	Oil and apply paste on exit belt
Double convoyer belt	Apply oil on the mat's elevating system and liquid paraffin to the mat's rotating drums' spindles
Empty station	-
Head	-
Tables	-
Basement	-

Table 7 – TPM lubrication tasks for TAP-5 press

TPM		
Equipment	**Cleaning and inspection**	
	Components	**Tasks**
Feeder	-	-
Rams	Transfer, rams, table’s rails, table’s fixators, closing box, floor and support’s stems	Checking for leaks, clean ram, and check lighting, clean supports and check fixers and fixing sensors
Convoyer Belt	Closing box, exit belt, upper closing box and general	Cleaning the closing box, check belt condition and alignment, clean engines and spindles, check plugs and wiring and check lighting
Double convoyer belt	Exit belt, scrap rack, rack’s convoyer, floor, table and bases	Check and clean exit mat, check condition and alignment of the exit belt, check engines and lubricate spindles, check plugs, wiring and emergency pushbuttons, check rack condition, check labels and empty rack, check condition and clean convoyer, clean end of line tables and bases and sweep floor
Empty station	-	Check lighting, check and clean oil leaks and check the condition of pressure gauges
Crown	-	Cleaning and checking for oil or air leaks, clean engines ventilation flaps, check pressure gauges and distributors’ condition and check and test intermittent signaling
Tables	Transfer, end of line boxes and rails, cables and hoses, regulating valves and the tables	Check and clean air intakes, electrical, solenoid valves, and fixators, clean boxes, guides and electrical rails on the ground, check hoses, sensors’ cables, and electrical outlets, check air pressure regulators and outlets and clean table’s surface and scrap on steps
Basement	Hydraulic group, cushion’s air tank, cushion, cushion tank, lubrication tank, recycling reservoir and scrap conveyor	Check electrical and hydraulic connections, check and repair oil leaks, clean engines and oil tank, clean and check piping connections conditions as well as air leaks, clean air tank, clean walls and piping, check electric, pneumatic and hydraulic connections and check cushion level (empty if it’s too high)

Table 8 – TPM cleaning and inspection tasks for TAP-5 press

To help execute TPM tasks, workers have available what is called *Point to Point Lessons*. These are technical standard work sheets which contain every step of a TPM task as well as pictures to help visualize each step.

Aside from the everyday TPM tasks, there are improvements which are made within TPM scope such as the example shown below.

Figure 15 – Oil recycling system

In figure 15, what is shown is an oil recycling system which was created because one of the rams' components needed to be lubricated at all times, causing oil to drip constantly. The system allowed oil to be collected by a funnel and directed to a reservoir to be reutilized.

Figure 16 – Water collecting system

Figure 16 shows an air conditioning's water collecting system. What happened before was that water made by the air conditioning dripped all over the machine. The water collecting system allowed the machine to be kept dry.

4.7.2 5S

The 5S lean tool stands for *seiri* (organization), *seiton* (tidiness), *seiso* (purity), *seiketsu* (cleanliness) and *shitsuke* (discipline). Briefly reviewing, 5S aims to eliminate any unnecessary movements, implement a set of control techniques (which enable the desired standards to be met), create habits of maintaining a clean workplace, standardized procedures and maintaining them on a long-run (Becker, 2001). Some examples of 5S implementation in Stamping can be visualized below.

In figure 17, it can be seen that computers had cables all over the place, causing confusion when it was needed to know which was which. Work place safety was also an issue, since in the previous situation anyone who would pass by could stumble on the cables. After everything was routed, work stations improved visually and safety problems were eliminated.

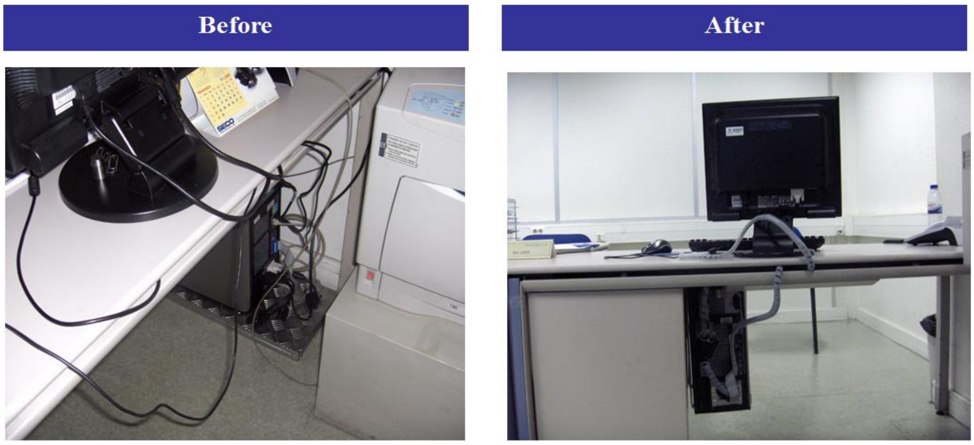

Figure 17 – 5S Example #1

In figure 18, machine components were scattered in a pallet. This meant that workers had to carry heavy equipment parts to its destination, which translated into wasted time and additional effort. The solution was devised by the plant's workers themselves, which was making a small car with spare materials in the plant. This allowed them to move equipment parts faster and with little or no effort to its destination.

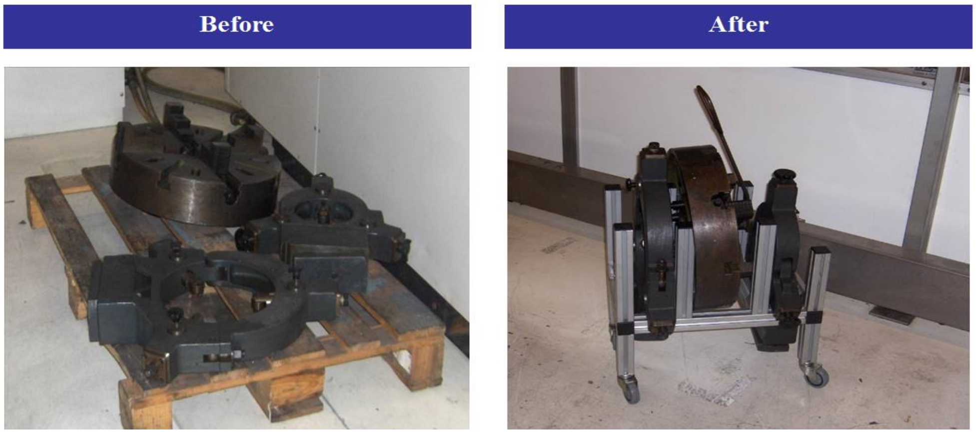

Figure 18 – 5S Example #2

In figure 19, the previous situation was that layouts of areas had incorrect markings. After the 5S implementation, the space occupied by the equipment was reduced and its individual location became more accurate.

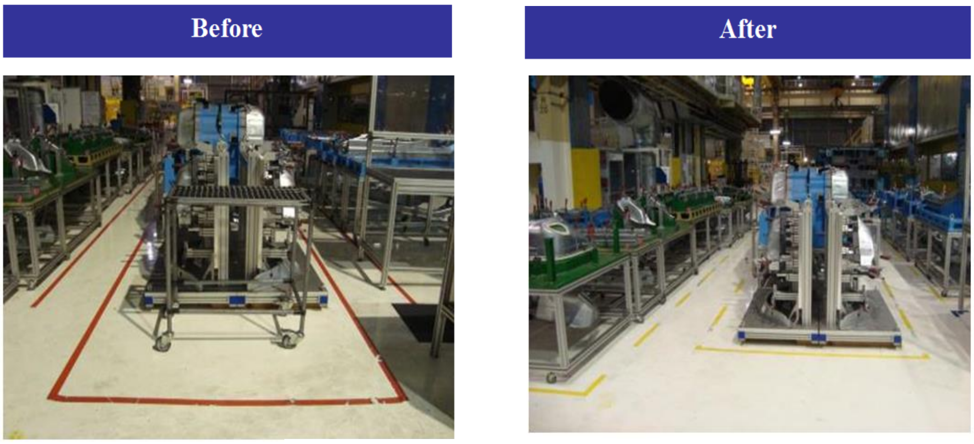

Figure 19 – 5S Example #3

On a daily basis, 5S tasks are divided into four types: organization; check markings on the floor, labels and visual signs; inspection, cleaning and lubrication standards; and cleaning of the floor and its surrounding areas. In addition, the first kind of tasks (organization) is to apply 5S methodology of having "*a place for each thing and each thing in its place*", while the remaining of task types are self-explaining.

4.8 Results analysis and discussion

Pointing out what was indicated in chapters 3 and 4, data prior to March of 2017 was gathered indirectly with information from the company's internal data base, as well as through informal interviews with the production's coordinator and team leaders. For that reason, diagrams constructed with information prior to March of 2017 are based solely on information gathered from the company's data base and confirmed through informal interviews with the press' team leader and production coordinator.

The impacts originated from design improvements are distributed in this chapter by the following categories: changeover process; changeover times; results validity; OEE; economic impact; and lean tools.

The results are summarized as an improvement in processes when operating the press, as well as a better arrangement between automatic and manual changeover tasks. Regarding changeover times, a significant reduction was achieved, which translated into an increase in the press' OEE and an economic benefit to the company. The improvement was proven to be significant and the lean tools associated were beneficial.

4.8.1 Changeover process

Visually, the impact is significant, since the feeder is completely new and different from the one before, in the way that it didn't have the robots and automations the new one has. Because the feeder was introduced into the press, the changeover process needed to be updated.

By comparing internal setups, before and after the design improvement (described in chapter 4.6 and in its sub-chapters), the new processes allowed a rearrangement of internal and external tasks, which reduced setup times in 6,546 minutes.

This improvement was achieved by converting manual operations 1, 5, 12 and 13 (of the internal setups diagram from before the design improvement in annex II) from internal setup into external setup, and by executing manual operations 6 and 7 (from the referred diagram) in parallel. However, this improvement didn't result directly from the application of SMED's conceptual stages. Another setback is (as it was referred in chapter 4.4.1) related to the new feeder which implicated a new set of die change tasks, more specifically internal setup operation 4 (described in table 6, from sub-chapter 4.6.2). But overall, the new tasks created are in smaller number than the ones made external or in parallel, which justifies the improvement made.

Design improvements are inserted in the last stage of SMED's three stage methodology. In substance, this type of improvement allows a technological leap, which introduces modifications in changeover tasks. If the methodology is applied fully in its concept, it would act as a reset button, meaning that the changeover process is once again available for SMED to be applied (identify new internal and external tasks; convert new internal tasks into external; and streamline).

The concept introduced in the previous paragraphs is represented in diagram 4, which estimates how SMED's methodology cycle should flow. Through informal interviews and data gathered from the company's internal data base, it was able to confirm that SMED improvements follow the cycle described. After that, SMED was applied reducing changeover times, reaching a point where making internal tasks into external wouldn't produce significant results.

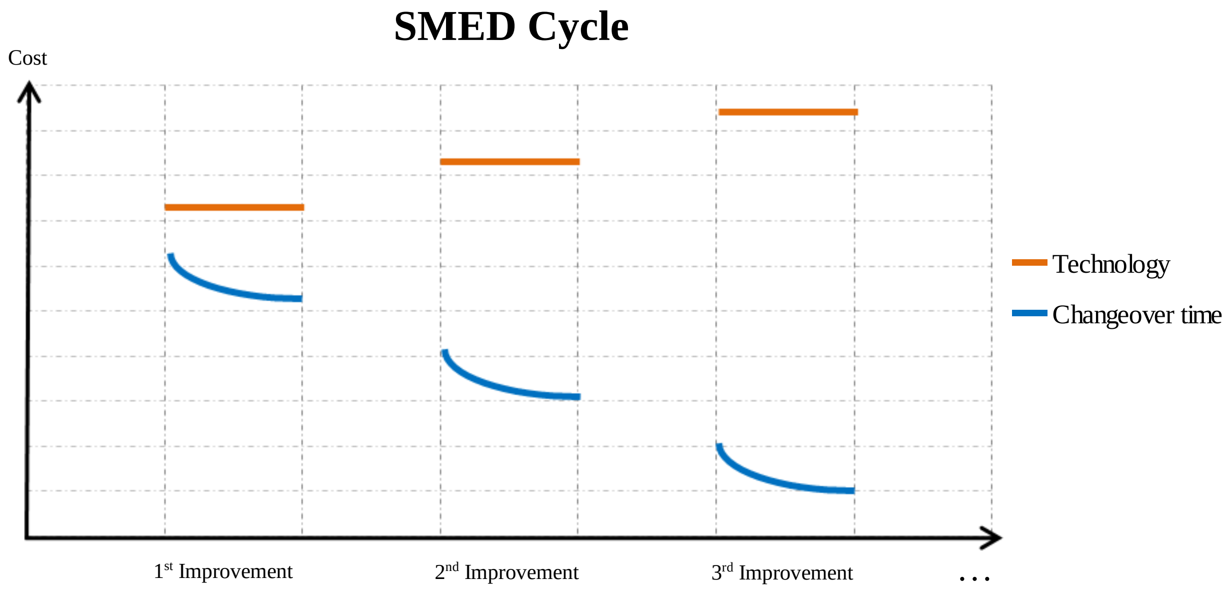

Diagram 4 – SMED methodology estimated cycle

Therefore, to further reduce changeover times, a design improvement is implemented. This elevates technology to a new stage and with new setup processes, which enables SMED's three conceptual stages to be applied once again until it reaches a point where making internal operations into external ceases to decrease changeover times significantly. This process is repeated (ideally) until the final goal of SMED is achieved, which is to reach a changeover time under 10 minutes.

This concept was able to be confirmed by the case study. The design improvement described throughout this study represents the jump between the first and second improvements in diagram 4. In the months following this study, the focus will be to apply SMED's three stage methodology once again, to the new changeover processes, and reduce setup times through organizational improvements. When organizational improvements cease to provide significant improvements to changeover times' reduction, a design improvement will be equated once more. Future design improvements will also contemplate the implementation of new organizational improvements (as it is described in the third improvement of diagram 4).

The results presented in the previous paragraph support the concept presented in chapter 2.3.4, which identifies design changes as part of the third stage of SMED's conceptual stages (which is to streamline changeover setup operations).

By comparing the spaghetti diagrams after and before the improvement (figure 20), the conclusion is that the differences trace back to the feeder's exchange tasks, which didn't exist before. Since these tasks are new, they are open to improvements by SMED, because of the cyclical characteristic highlighted in the previous paragraphs.

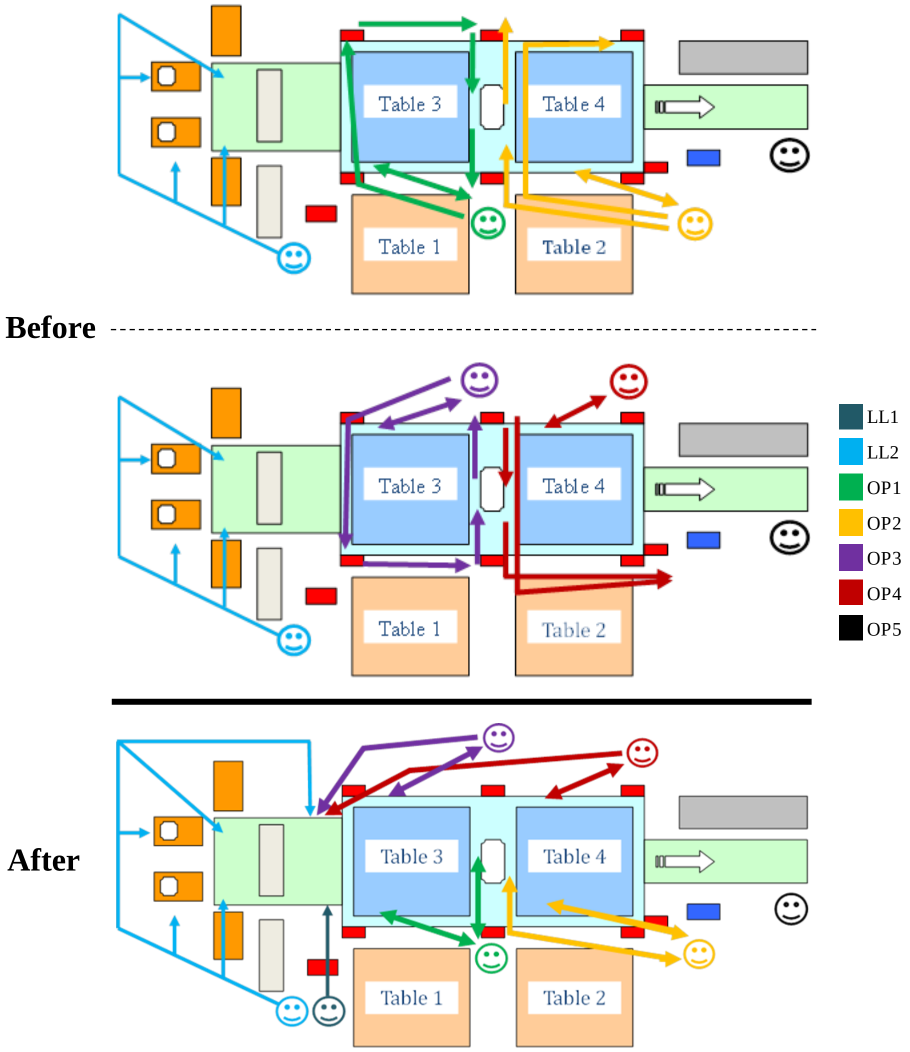

Figure 20 – Spaghetti diagram before and after design improvement

Previously, there were four operators responsible for exchanging middle stations' grippers and idle station's jigs. The fifth operator was responsible for adjusting the convoyer belt, while the line leader placed the feeder and press in die change mode, closes previous production and opens the next one, changes the feeder's automation, inserts pallet into the feeder, before placing it on automatic setting and start production.

With the introduction of the new feeder, the exchange of middle stations' gripper jigs is executed by operators 1 to 4. Then, operators 1 and 2 perform the exchange of idle stations jigs, while the other two (3 and 4) executed the exchange of Rz's automations. Operator 5 remains with the same task of adjusting the convoyer belt. An additional line leader (LL1) was incorporated in the team, which job is to move Rz out of position so its automations can be exchanged. The other line leader (LL2), on top of its previous tasks, helps operators 3 and 4 performing the exchange of Rz's automations.

At a first glance, what can be easily visualized is that the operators' movements, during the changeover process, became more organized and the operators ceased switching from one side of the press to the other. This rearrangement enabled reducing distance travelled by the operators and line leaders in 14m (from 105m, to 91m).

4.8.2 Changeover times

Overall, changeover times suffered significant decreases with the improvement made. Internal setups decreased from 22,290 to 15,744, which translated into approximately six and a half minutes of saved time. Annually, time saved reach a total of 18.443,896 minutes, which converts into approximately 12 days, 19 hours and 24 minutes (table 9).

	Current	Before design improvement	Time Saved						
			Per Change (min.)	Daily (min.)	Weekly (min.)	Monthly (min.)	Annual (min.)	Hours	Days
Internal setups	15,744	22,290	6,546	58,914	353,484	1.536,991	18.443,896	307,398	12,808

Table 9 – Press exchange times and savings

Another conclusion taken by the results shown in table 10 is that internal setups take up to approximately 62% of the changeover times. These statistics reinforce the need there is to convert internal setups into external setups. That is why the company strives to keep reducing internal setups tasks, by applying on a daily basis a continuous improvement philosophy at all levels.

Setups (Current)				
Setups	**Start**	**Finish**	**Time**	**%**
External I	-19,000	0,000	19,000	-
Run-Down	0,000	6,500	6,500	25,75%
Internal	3,000	18,744	15,744	62,37%
Run-Up	18,744	25,244	6,500	25,75%
External II	13,343	88,843	75,500	-
Total			**25,244**	

Table 10 – List of press' exchange of dies setups with relative statistics

Being able to reduce internal setup times (even if it's only by a single minute) can have significant impacts. These impacts are perceived just by looking at the example given by this case study, where the improvement made by reducing internal setup times (in approximately 5 minutes), translates into substantial benefits and savings, even on a short run.

When it comes to a point, where it’s not possible to reduce setup times in a significant way with the current design, a design improvement offers a solution, by introducing new technology to the press and, therefore, providing a design upgrade which would increase parts produced as well as increasing efficiencies.

Because of the design improvement, die change times for the year of 2016 were considerably high, even in comparison with the 22,290 minutes of average die change time fixated until the design improvement at the end of 2015. However this adjustment period is necessary and an increase of die change times was expected. The tendency referred can be visualized in diagram 5. From January to February there was a significant increase, with February being registered a maximum average die change time of 26 minutes. In the following months, average die change times decreased and stabilized from September forward at 14 minutes, with November registering one minute above the tendency referred.

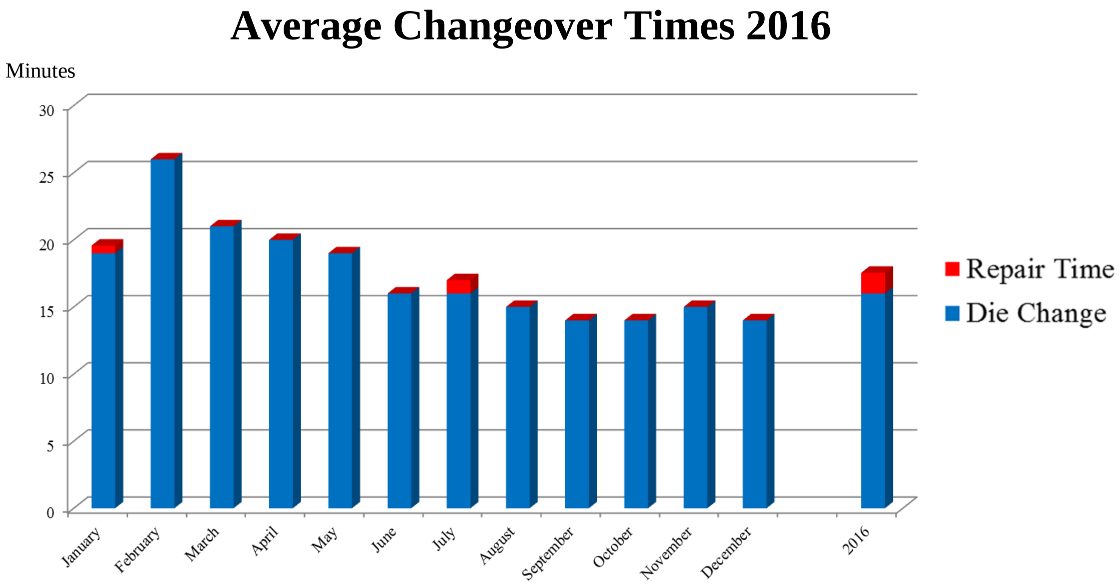

Diagram 5 – Average changeover times in 2016

Shifting the attention to the year in which the study was conducted (2017), with the available data for the first semester, it can be seen in diagram 6 that there was a setback which resulted in an increase in average changeover times.

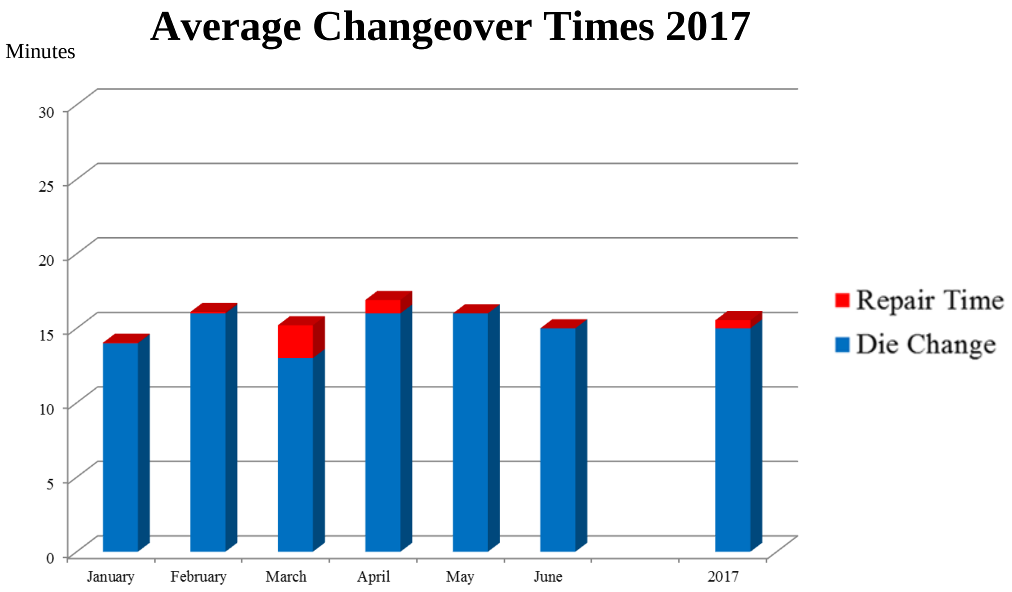

Diagram 6 – Average changeover times for the first semester of 2017

In January, die change times were in average the same as the last quartermaster of the previous year (2016), reaching 14 minutes. February registered a 2 minutes increase in average changeover times.

Difficulties started on the following months. Even though there was a decrease in 1 minute in comparison with February, March's 15 minutes die change times included 13 minutes of die change (the lowest registered in the years of 2016 and 2017), but also 2 minutes of average repair times. In April, dies change times increased 2 minutes, in average, totalizing 16 minutes of average die change time. Furthermore, average repair times were of 1 minute, which increased average setup times to a year maximum average of 17 minutes. In May total average die change times decreased 1 minute, settling at 16 minutes. June came to verify the downward trend of die change times with a total average die change time of 15 minutes.

The reasons behind the increase of die change times, which started in November of 2016, are that an identical design improvement was being made to the TAP-5's twin press (TAP-6), for that reason production from TAP-6 was temporarily allocated to TAP-5. Since one press produced mainly interior parts and the other exterior parts, changes lasted a bit longer because there were additional tasks that weren't normally performed. However, after TAP-6's design improvement had finished, normal production resumed at TAP-5 and die change times started to decrease.

Concluding the topic, looking at the average die change time for 2017, which is of 14,750 minutes, it is very close to the 15,744 minutes set as target for a die change.

4.8.3 Results validity

Regarding the validity of the results presented, data related to average setup times, after the design improvement, were gathered through direct observation, while average setup times collected through data from the company’s internal data base and informal interviews. Sample size is of 36 observations and the tests were conducted assuming a 95% confidence interval of the difference.

To infer that the difference between setup times is significant, a Student’s T-test was conducted. This test is used when the objective is to determine if two sets of data are significantly different from each other. In this particular case, the objective is to determine if two independent samples are significantly different from each other. To be able to use this test, there are two assumptions which need to be verified: the test statistic needs to follow a normal distribution; and the samples need to be homogeneous.

The number of observations (36) allows verifying the first assumption of having the test statistic follow a normal distribution, by means of the *Central Limit Theorem* (CLT). The CLT enables assuming that the test statistic approximately follows a normal distribution when the samples’ size is moderately large, i.e. greater than 30.

About the second assumption (homogeneity), this is verified by Levene's test for equality of variances. This test’s hypotheses are the following:

H_0: population’s variances are equal.
H_a: population’s variances are different.

The outcome of the test translates into a p-value of 1,000, which is greater than the significance level of 0,05. Because of that, the null hypothesis is not rejected. Thus, the necessary assumptions to perform a student’s T-test are verified.

Student’s T-test has the following hypotheses:

H_0: population’s averages are equal.

H_a: population’s averages are different.

The test’s results are of a p-value of 0,000, which is inferior to the significance level of 0,05 and the null hypothesis is rejected. Therefore, there is statistical evidence to infer that the average die change times before and after the design improvement are significantly different from each other.

4.8.4 OEE

Revisiting the concept introduced in the literature review (topic 2.2.4), overall equipment efficiency (OEE) is a way to measure the efficiency of a production plant, by taking into account all losses and is calculated as:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (6)$$

Analyzing each component of OEE, availability considers all events which cause production to stop long enough to find out why it stopped and is calculated in the following way:

$$\text{Availability} = \frac{\text{Run Time}}{\text{Planned Production Time}} \quad (7)$$

Performance is a ratio which considers anything that may cause production not to be running at maximum speed, such as slow cycles or small stops. The formula which calculates performance is the following:

$$\text{Performance} = \frac{(\text{Ideal Cycle Time} \times \text{Total Count})}{\text{Run Time}} \quad (8)$$

Quality is a ratio which takes into account parts which don't meet quality standards, reworks included, and it's calculated the following way:

$$\text{Quality} = \frac{\text{Good Parts}}{\text{Total Parts Produced}} \quad (9)$$

Regarding the press' OEE in 2015 (before the design improvement), for the first semester it ranged between 27,8% and 48,5%, never going above the 50% mark. Aside from July, the second semester can't be considered in terms of comparison because it was when the design improvement was taking place.

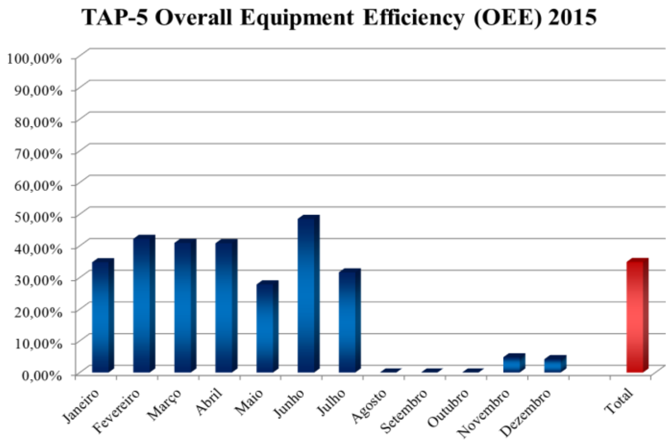

Diagram 7 – Press' overall equipment efficiency in 2015

About TAP-5's OEE in 2016, it can be seen that the tendency is to increase (diagram 8). The year began with the lowest OEE (9,8%), but it rapidly gained momentum and since May stabilized between 40% and 50%.The peak was reached in November with an OEE of 58,3%.

Analyzing data on diagram 9 of the year the study is being conducted, so far it has been following the previous year tendency with OEE ranging between 31,3% and 51,2%. The lowest OEE was achieved in February, while the highest being recorded in May. In average, OEE for 2017's first semester was of 41,10%, whereas in 2016 and 2015 the OEE was of 33,37% and 39,17%, for the first semester respectively.

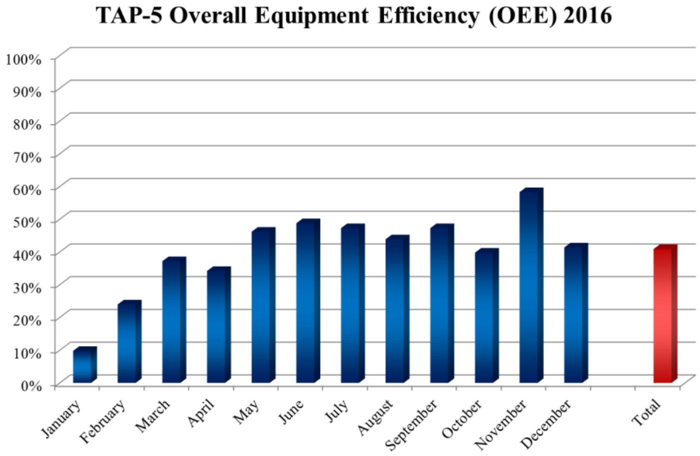

Diagram 8 – Press' overall equipment efficiency in 2016

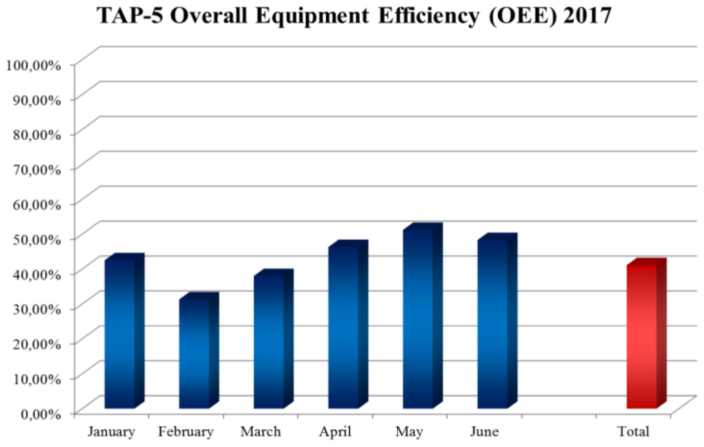

Diagram 9 – Press' overall equipment efficiency in 2017

4.8.5 Economic impact

This subchapter provides an estimate on the improvements viability from an economic point of view. With the main indicators to be analyzed are the payback period and the investment's net present value.

Calculations presented in this subchapter are based on the following data:

- Working days – 230.
- Nº of shifts:
  - Per day – 3;
  - Per week – 18.
- Nº of die changes:
  - Per shift – 3;
  - Per day – 9.
- Press' top speed – 16 strokes/min.
- Up-time – 87%.
- Parts produced – 17/min.
- Saved time (design improvement) – 6,546 min/die change.
- Design improvement investment – €5.439.300.

The first concept which needs to be materialized is the loss generated by the machine being stopped or not producing at standard speed and quality.

$$\begin{aligned} & Loss\ from\ stoppage\ times \\ & \qquad = (Direct\ costs + Indirect\ costs - Scrap\ value) * parts/min = \\ & \qquad = €0{,}77/part * 17\ parts/min = \\ & \qquad = €13{,}09/min. \quad (10) \end{aligned}$$

Direct costs include the press' line workers and consumables (such as electricity, water or oil). Indirect costs are calculated through a distribution key, which gives a ratio that divides total indirect costs by each press (considering strokes made, personnel allocated to it and other factors). The ratio associated to TAP-5 is of 17,38%.

By making a rough comparison between stoppages caused by die changes (before and after the design improvement), losses were reduced from €291,78 to €206,09. This reduction of €85,69 per die change comes from SMED's design improvement which was able to reduce die change times from 22,290 min. to 15,744 min..

Regarding the payback period indicator, it gives the time of the return on an investment, by dividing its cost by the annual gains resulted from the improvement. The general idea of this concept is that the longer the period, the less desirable is the investment. Unlike the other indicator which will be analyzed further ahead (NPV), the payback period doesn't consider the time value of money.

$$Payback\ Period = \frac{Investment}{Anual\ Gains}\ (11)$$

Weekly savings are calculated by multiplying the number of minutes saved by six working days by the number parts produced per minute by the cost of producing one part. Being the minutes saved per day of 58,914 (6,546 min./change * 3die changes * 3shifts), the number of parts produced per minute of 17 and the cost of producing one part of €0,77 (direct and indirect costs minus scrap value per part). Overall, weekly savings, related to the die change time's reduction, reach €4.476,98, which if it is assumed that in one year there are 52 available work weeks, the result is a saving of €232.803,19 per year. Since it's estimated that production increases from 3.627.498 parts to 5.049.477 parts, because of an increase in strokes from 10 to 13,92 strokes/min., the increased benefits are expected to be of €1.088.832,35, which are calculated by multiplying the increased number of parts by 0,77€/part (value by which the company would sell a part). Total annual gains are estimated to be of €1.321.635,54.

$$Payback\ Period = \frac{5.439.300}{1.321.635{,}54} = 4{,}12\ years\ (12)$$

Taking a look at the result from the payback period, the conclusion is that, if the time value of money isn't considered, the investment has its return in approximately four years.

Shifting the attention towards the NPV, it translates the difference between the present value of cash inflows and the present value of cash outflows (as it is shown in formula 13), i.e., the difference between the savings from the design improvement discounted to "today" and the investment made "today". If the NPV is positive it means that the earnings exceeded the costs, which generally mean that if the investment has a positive NPV it will be a profitable one and, on the other hand, if an investment has a negative NPV it will result in a net loss.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} - C_0\ (13)$$

To calculate the NPV of the investment related to the design improvement, it will be considered that the investment for the design improvement is valued at €5.439.300, has a constant annual saving of €1.321.635,54 throughout 20 years (which is estimated time in which the equipment is expected to generate return) and an interest rate of 0,823%. The interest rate presented is the equivalent of the company investing in 20-year German government bonds (taken on June 6, 2017 at 2:16:39 p.m.). The investment's profitability resulted from the NPV is of €18.840.811,47.

Assuming the company's sales value for 2016 of €1.529 billion, with an investment which represents 0,356% of 2016's sales, it is able to obtain annual savings of 0,086% of 2016's sales, whereas the NPV represents 1,232% of 2016's sales.

The conclusion, which can be taken from analyzing the payback and NPV indicators, is that SMED's design improvements can provide significant improvements (as it was demonstrated in sub-chapter 4.8.3) with a considerable return (NPV = €18.840.811,47) and in a very short period (payback period ≈ 4 years).

4.8.6 Lean tools

Out of all the lean tools and techniques listed in the literature review, the ones which are applied on a daily basis in the Stamping area are TPM and 5S (aside from SMED).

As it is shown in sub-chapter 4.7, TPM and 5S's impacts are easily visualized and improvements, such as timed saved, safety and health, ergonomic conditions or work environment, are easily perceived. Its application is made across the entire area, whether it's next to the presses or in the offices. Having every single person taking part in this process also helps develop a lean culture which will become the foundations for sustainable SMED improvements, or from other lean methodologies.

5. Conclusion

The goal for this thesis is to describe the implementation of SMED in the automobile industry, i.e., in an environment for which it was devised for, and confirm if waste was reduced (mainly by reducing setup times).

To accomplish this goal, the study was conducted in an automobile manufacturer, in the stamping press area, more specifically in a triaxial press. The improvement's steps, made by SMED, were described, its results and impacts were analyzed and the effectiveness of the referred lean technique was verified.

Taking a second look at the fifth paragraph of chapter 2.3.6 *Critics and limitations to SMED*, the SMED project implemented in TAP-5 press made its impact through a *design* improvement. This fact supports McIntosh *et al.* (2000) critics of a direct application of SMED in a mature lean environment producing results with little significance. On the other hand, implementing design changes to reduce setup times and/or increase efficiency end in more significant results.

To finalize, there was a sub-product which resulted from the study, namely lean tools/technique which complements SMED. This sub-product was expected to be obtained and, therefore, listed as an objective.

5.1 Research question and propositions breakdown

Reviewing the research question: *how setup times and waste were reduced through the implementation of SMED in a Volkswagen automobile manufacturer production cell?* Having reached the end of the study, the answer is that setup times were reduced through a design improvement, within a SMED initiative. Furthermore, other lean tools were used as a complement to SMED. The referred lean tools are TPM and 5S, and are important in building foundations for SMED, as well as for maintaining it on a long run.

This sub-chapter revisits the propositions in sub-chapter 3.3 and confronts the initial ideas, designed to act as guidelines for the study, with the study's results. The referred analysis is presented in the paragraphs below.

P1 – the implementation of SMED resulted in the reduction of the setup times.

This proposition was proven to be true, as changeover times were reduced in 6,546 minutes per change. The time reduction was proven to be significant (see sub-chapter 4.8.3 for more detailed information). This reduction was achieved by a design improvement in a SMED's initiative scope. As it was pointed out in the literature review, design changes are inserted in the third stage of SMED, which is to streamline all operations of the changeover process (R. McIntosh et al., 2007).

P2 – through SMED it is possible to reduce setup times to a single digit minute.

Even though the improvement enabled a significant reduction of changeover time, the final goal of reaching a die change time under 10 minutes is yet to be reached. Currently, die change time is at 15,744 minutes, with a total changeover time of 25,244 minutes. To achieve the 10 minute mark, it is necessary to reduce approximately 6 minutes of the die change setup.

P3 – elimination/reduction of non-value adding tasks related to tasks such as materials and equipment misplacement.

This proposition was verified, and is greatly because the design improvement introduced new automations and forced a rearrangement of previous tasks. The final result can be visualized in figure 14, where the operators' movements are described. Regarding poor placement of material and equipment (aside from SMED), there are complementary lean tools like TPM and 5S (described in sub-chapter 4.8.6), which initiatives enable reducing transportation and searching times.

P4 – increase in the standardization of changeover operations.

Since design improvements are inserted in the third stage of SMED (streamline), this proposition is promptly verified. The design improvement involved a rearrangement of changeover tasks. These tasks were timed, charted and trained by the operators so that die changes are executed in the targeted time.

P5 – constant improvement of the changeover process which is the final step in implementing SMED.

This proposition links with P2, which revealed a six minute window of changeover time that can still be reduced.

5.2 Research limitations

Findings reported in this thesis are within the scope of the research's limitations. A portion of these limitations are inherent to case studies, which is not being able to be generalized (Patton & Appelbaum, 2003). On the other hand, the theoretical propositions of this research can be generalized (Yin, 2003).

Aside from the limitation of the research being a case study (as described in the previous paragraph), the main limitation has its source in the timeline which the study was conducted, which is having data collected prior to March 2017 gathered indirectly with information from the company's internal data base, as well as through informal interviews with the production's coordinator and team leaders.

The contribution this thesis offers is of an insight into a successful implementation of a lean technique (SMED) in an original environment, for which it was designed in the first place. As it was identified by Marksberry *et al.* (2010), research of this nature is listed as a gap in the literature. Therefore, this research's findings adds knowledge to a segment of lean research which has been somewhat in the dark.

Remembering the thesis goal, it is to describe how setup times and waste were reduced through the implementation of SMED, in a Volkswagen automobile manufacturer's production cell. The other limitation regarding the study was that the improvement was design based. It would be more complete if there had been the opportunity to observe an implementation of SMED in all its conceptual stages, focusing not only on design improvements but also on organizational improvements. This would allow a full insight into the methodology at all levels.

5.3 Further investigation

Even though research about SMED and other lean tools is very common, investigation in how it has developed in its original environment, i.e. in the automotive industry, is limited. This study aims to help fill in this gap, by providing an insight on the application of SMED in a company which gathers the referred features.

Directing the attention towards lean, in the literature studied it was promptly identified by Marksberry *et al.* (2010) that few studies explore the fact that if lean is implemented incorrectly it can have negative impacts, such as weakening workers' involvement.

Considering that the study focused on a segment of SMED, which is design changes, it would be natural that further research should be heading for the implementation of SMED's previous conceptual stages and compare the results. A comparison between these studies would help to understand if applying SMED in the automotive industry, where lean philosophy is fully developed, organizational improvements made by only applying the conceptual stages, i.e. identifying internal and external setups and converting internal into external setups, are more significant than design improvements. If not, then the conclusion would be that on a long run the methodology should contemplate a point where only design changes can provide significant improvements in reducing changeover times.

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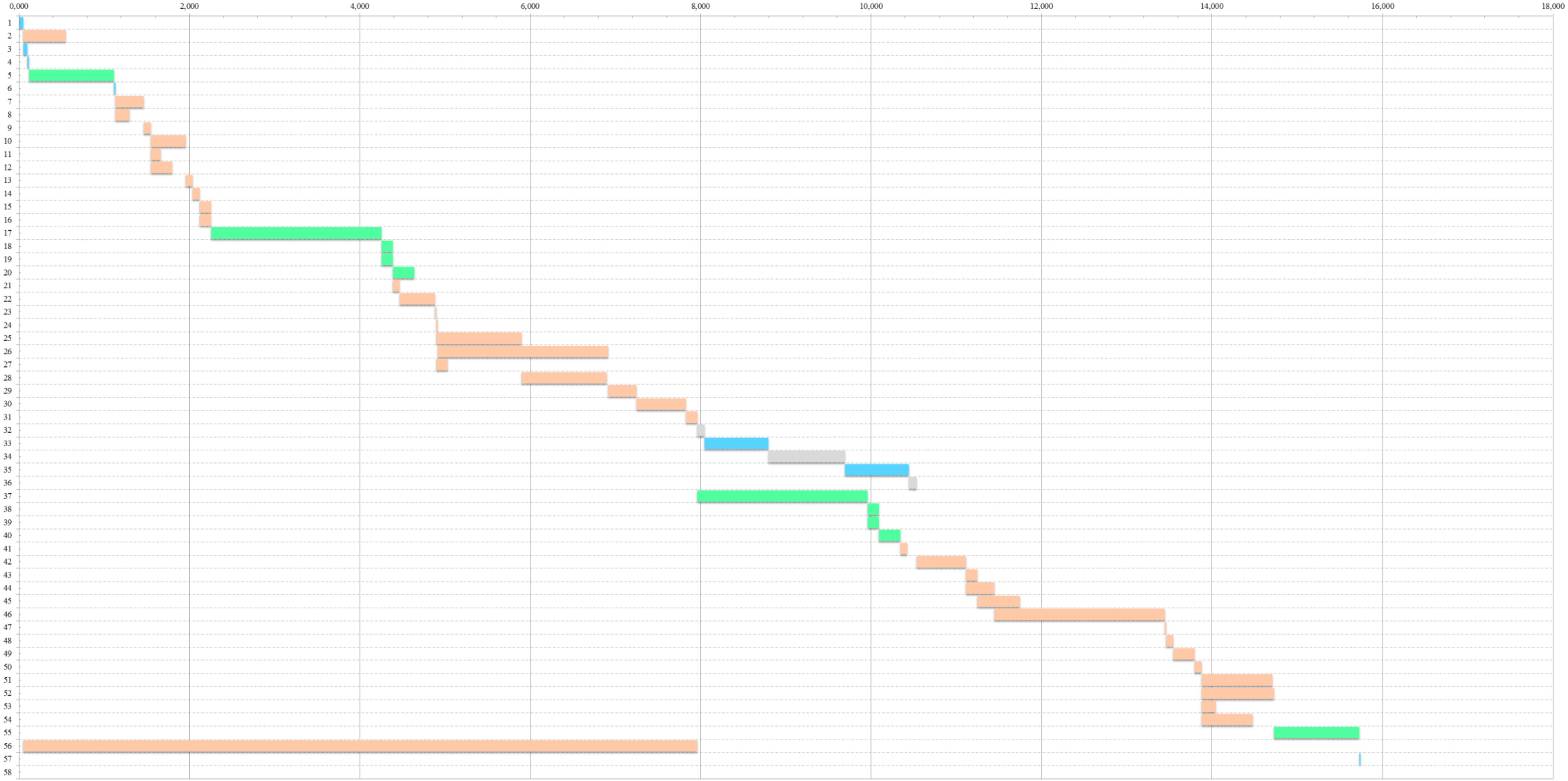
Annexes

I

		Die Change - Internal Setups Diagram (After Retrofit)					
		Nº	Press Setup	Setup	Start	Finish	Time
B0		1	LL1	0.1 - Place Feeder in EoD mode and initiate Feeder EoD	0,000	0,050	0,050
		2	PRESS	0.2 - Feeder's axis regulation and place Robots in exchange position	0,050	0,550	0,500
		3	LL1	0.3 - Move Press to the Top Dead Center (TDC)	0,050	0,100	0,050
		4	LL1	0.4 - Put Press in EoD mode	0,100	0,116	0,016
		5	OP7	0.5 - Move exit mat to EoD position	0,116	1,116	1,000
		6	LL1	1.0 - Initiate EoD on the Press	1,116	1,132	0,016
B1		7	PRESS	4.0 - Adjust hammers to correction position	1,132	1,465	0,333
		8	PRESS	4.1 - Get cushion down	1,132	1,298	0,166
		9	PRESS	5.0 - Press to the Bottom Dead Center (BDC)	1,465	1,548	0,083
		10	PRESS	7.2 - Uncouple Press transfer	1,548	1,958	0,410
		11	PRESS	7.3 - Release upper part of die	1,548	1,664	0,116
		12	PRESS	7.4 - Regulate transfer's transversal to exchange position	1,548	1,798	0,250
		13	PRESS	11.0 - Transfer at 100 degrees	1,958	2,038	0,080
		14	PRESS	13.0 - Press at TDC	2,038	2,121	0,083
		15	PRESS	15.0 - Open front doors	2,121	2,254	0,133
		16	PRESS	15.1 - Open back doors	2,121	2,254	0,133
B2		17	OP3/4/5/6	17.0 - Exchange middle grippers and confirm at button	2,254	4,254	2,000
		18	OP3/4	18.0 - Close front doors (manual)	4,254	4,387	0,133
		19	OP5/6	18.1 - Close back doors (manual)	4,254	4,387	0,133
		20	OP3	25.2.3 - Activate warning signals on tables' exit side (manual)	4,387	4,637	0,250
B3		21	PRESS	21.0 - Transfer at 204 degrees	4,387	4,467	0,080
		22	PRESS	22.0 - Get empty station's supports down	4,467	4,882	0,415
		23	PRESS	23.0 - Exchange data	4,882	4,898	0,016
		24	PRESS	25.0 - Elevate clamps bars' supports	4,898	4,914	0,016
		25	PRESS	25.4 - Regulate empty station supports' transversal	4,898	5,898	1,000
		26	PRESS	26.0 - Release clamps' bars	4,914	6,914	2,000
		27	PRESS	26.2.3 - Open doors from exit side	4,898	5,031	0,133
		28	PRESS	26.4 - Set empty station supports to work position	5,898	6,898	1,000
		29	PRESS	27.0 - Release and elevate tables	6,914	7,247	0,333
		30	PRESS	30.0.1 - Interior tables exit	7,247	7,827	0,580
		31	PRESS	33.0 - Open doors from new tables' entry side	7,827	7,960	0,133
B4		32	LL2+OP5/6	33 a) - Open Robot Z's door (manual)	7,960	8,043	0,083
		33	LL1	33 b) - Move Rz to EoD position	8,043	8,793	0,750
		34	LL2+OP5/6	33 c) - Exchange Rz's arms and confirm exchange	8,793	9,693	0,900
		35	LL1	33 d) - Move Rz to work position	9,693	10,443	0,750
		36	LL2+OP5/6	33 e) - Close Rz's door	10,443	10,533	0,090
B5		37	OP3/4	34.0 - Exchange empty station's supports and confirm (manual)	7,960	9,960	2,000
		38	OP3	36.0 - Close front doors (manual)	9,960	10,093	0,133
		39	OP4	36.1 - Close back doors (manual)	9,960	10,093	0,133
		40	OP4	39.1 - Activate warning signals on tables' entry side	10,093	10,343	0,250
B6		41	PRESS	40.0.1 - Open doors from tables' entry side	10,343	10,423	0,080
		42	PRESS	41.0.1 - Tables entrance	10,533	11,113	0,580
		43	PRESS	42.0.1 - Close doors	11,113	11,246	0,133
		44	PRESS	42.2 - Get tables down and fixate them	11,113	11,446	0,333
		45	PRESS	43.3 - Adjust hammers to new correction position	11,246	11,746	0,500
		46	PRESS	44.0 - Fixate clamps' bars	11,446	13,446	2,000
		47	PRESS	45.0 - Get clamps bars' supports down	13,446	13,462	0,016
		48	PRESS	48.0 - Press to BDC	13,462	13,545	0,083
		49	PRESS	49.0 - Fixate upper dies to hammer	13,545	13,795	0,250
		50	PRESS	50.0 - Press to TDC	13,795	13,878	0,083
		51	PRESS	53.0 - Couple transfer to Press	13,878	14,708	0,830
		52	PRESS	53.1 - Adjust hammer to work position	13,878	14,728	0,850
		53	PRESS	53.2 - Elevate cushion	13,878	14,044	0,166
		54	PRESS	53.3 - Adjust transfers' transversal to work position	13,878	14,478	0,600
B7	A	55	OP7	54.0 - Move exit mat to work position	14,728	15,728	1,000
	B	56	PRESS	54.1 - Exchange of feeder's die finished	0,050	7,960	7,910
		57	LL1	55.0 - End of EoD and place Press and Feeder in automatic mode	15,728	15,744	0,016
	C	58	PRESS	56.0 -Press ready to start production	15,744		
		Total					**15,744**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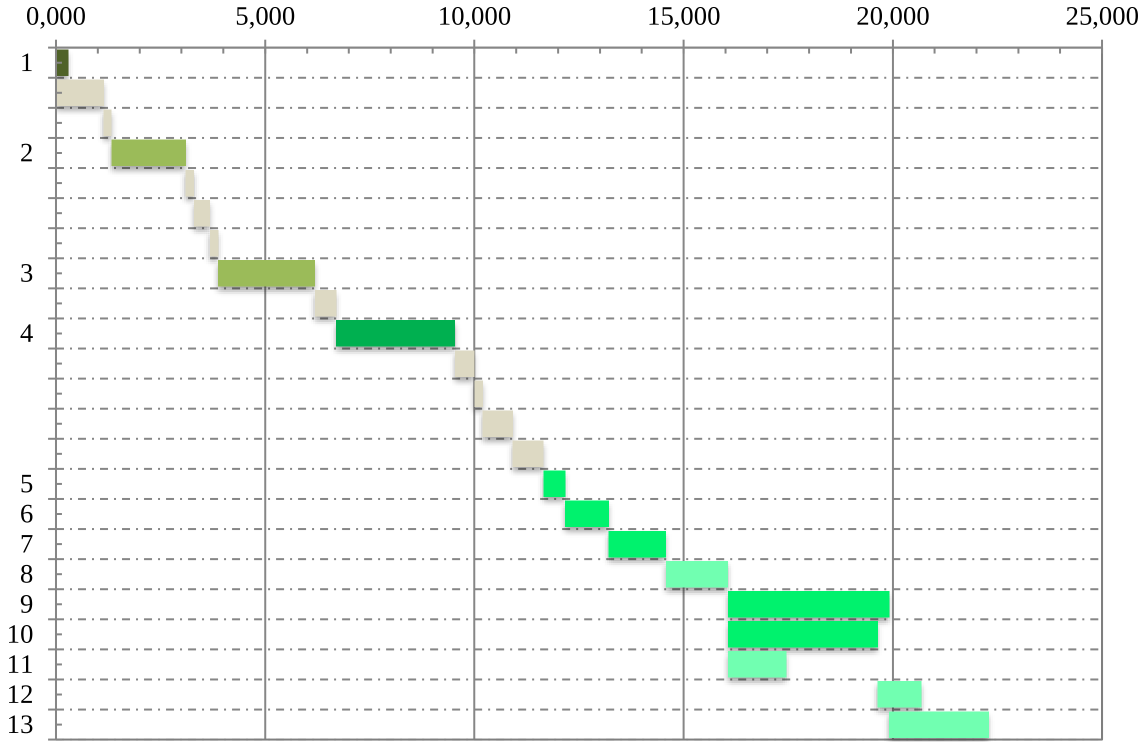
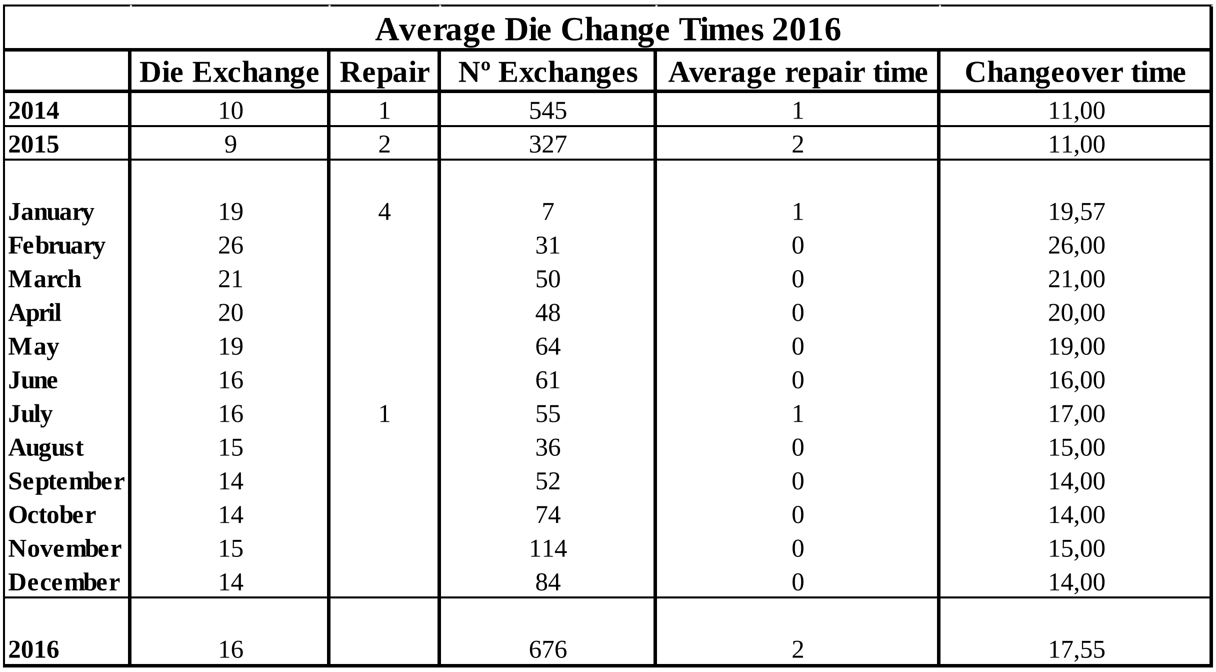
II

Die Change - Internal Setups Diagram (Before Retrofit)

N°	Press Setup	Setup	Start	Finish	Time
1	OP7	Get empty gripper car to press table	0,000	0,290	0,290
	PRESS	Unlock die set and open transfer	0,000	1,139	1,139
	PRESS	Open doors	1,139	1,329	0,190
2	OP3/4/5/6	Unlock grippers old production and Grab and place grippers for new production from platen to transfer (grippers from new production already removed from automation car to platen)	1,329	3,100	1,771
	PRESS	Close doors	3,100	3,303	0,203
	PRESS	Move transfer	3,303	3,681	0,378
	PRESS	Open doors	3,681	3,877	0,196
3	OP3/4/5/6	Continue unlock grippers old production and Grab and place grippers for new production from platen to transfer (grippers from new production already removed from automation car to platen)	3,877	6,190	2,313
	PRESS	Platen with old production moves out of press to die setting position	6,190	6,700	0,510
4	OP3/4	Readjust empty station's supports from station 079	6,700	9,540	2,840
	PRESS	Platen with new production moves inside press to production position	9,540	10,000	0,460
	PRESS	Close doors	10,000	10,197	0,197
	PRESS	Internal coupling die to press	10,197	10,916	0,719
	PRESS	Transfer automatic positioning	10,916	11,653	0,737
5	OP3	Get crane control + pin card	11,653	12,170	0,517
6	OP3	Remove old production grippers from front transfer to 1st platen	12,170	13,210	1,040
7	OP3	Remove old production grippers from front transfer to 2nd platen + automation car	13,210	14,580	1,370
8	OP5	Grab and place old production grippers from 1st platen front to automation car	14,580	16,060	1,480
9	OP3	Remove old production grippers from back transfer to 2nd platen + to automation car	16,060	19,910	3,850
10	OP3	Remove old production grippers from back transfer to 1st platen + to automation car	16,060	19,640	3,580
11	OP5	Remove supports from empty stations to automation car	16,060	17,450	1,390
12	OP5	Remove electrical cables and pressure hoses	19,640	20,680	1,040
13	OP5	Get wrench unscrew table screws from dies to platen + close scrap ramps	19,910	22,290	2,380

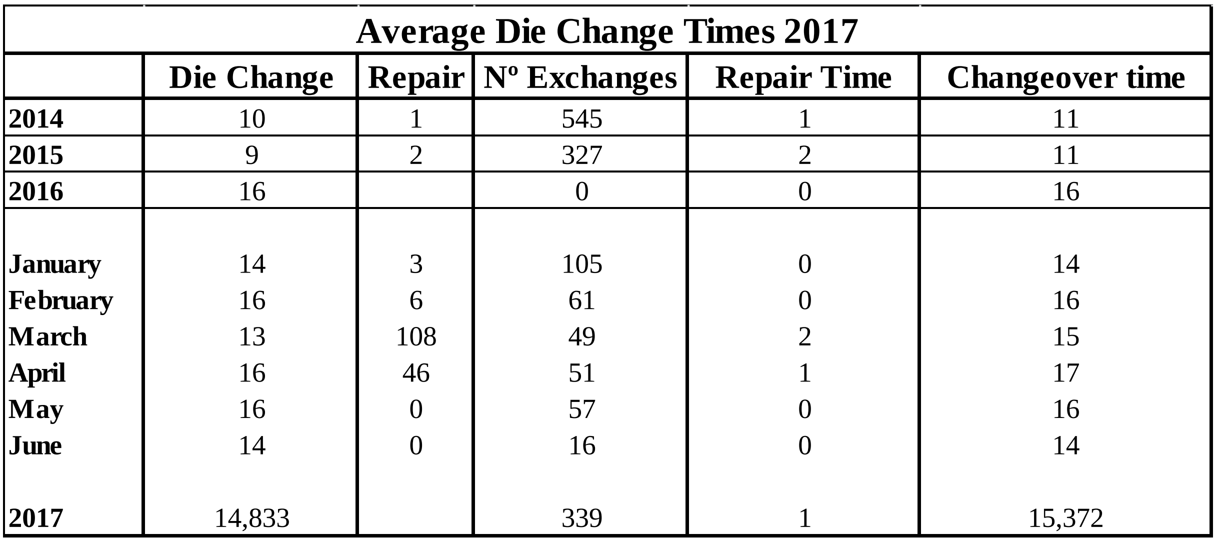


III



Average Die Change Times 2016

	Die Exchange	Repair	Nº Exchanges	Average repair time	Changeover time
2014	10	1	545	1	11,00
2015	9	2	327	2	11,00
January	19	4	7	1	19,57
February	26		31	0	26,00
March	21		50	0	21,00
April	20		48	0	20,00
May	19		64	0	19,00
June	16		61	0	16,00
July	16	1	55	1	17,00
August	15		36	0	15,00
September	14		52	0	14,00
October	14		74	0	14,00
November	15		114	0	15,00
December	14		84	0	14,00
2016	16		676	2	17,55



Average Die Change Times 2017

	Die Change	Repair	Nº Exchanges	Repair Time	Changeover time
2014	10	1	545	1	11
2015	9	2	327	2	11
2016	16		0	0	16
January	14	3	105	0	14
February	16	6	61	0	16
March	13	108	49	2	15
April	16	46	51	1	17
May	16	0	57	0	16
June	14	0	16	0	14
2017	14,833		339	1	15,372

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CASE STUDY ON THE DESCRIPTION OF THE IMPLEMENTATION OF SMED IN A VOLKSWAGEN AUTOMOBILE MANUFACTURER’S PRODUCTION CELL

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