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SMED implementation in electron beam machine applied in automotive industry

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Appreciations

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Resumo

Semelhante à invenção do avião, o surgimento do automóvel teve um impacto tremendo nas nossas vidas do dia-a-dia. A inovação e as cada vez mais repentinas flutuações de mercado globalização obrigaram a uma maior rapidez dos fornecedores (independentemente do seu nível) tornando-os ágeis e que consigam dar uma resposta rápida aos pedidos dos seus clientes. Por isso, podemos considerar que a indústria automóvel está inserida num dos mercados mais competitivos onde a mais pequena modificação de um *setup* mais pequeno faz parte da solução para o sucesso da empresa.

Novas filosofias, como a Lean, com métodos e ferramentas aliado a modelos de negócios inovadores podem ter a capacidade de reduzir custos e aumentar a produtividade, eliminando actividades sem valor acrescentado (desperdício) através da melhoria continua. Essas filosofias devem ser implementadas com muito cuidado pois a falha na sua implementação pode levar a tremendas perdas que podem ser irreparáveis. Algumas características são primordiais tais como empenho, comunicação, experiência e um espirito aberto para modificar/eliminar/criar actividades e ideias são chaves para o sucesso.

A revisão de literatura realizada para esta tese demonstra que existe já uma longa lista de programas de implementações SMED na indústria automóvel (onde nasceu a ferramenta) mas também nas restantes áreas da indústria. Porém, nenhuma dela foi efectuada em máquinas de feixe de electrões (ou irradiadores) independentemente do seu objectivo (um irradiador pode ser usado num vasto leque de industrias e serviços).

Sucintamente, este projecto foi desenvolvido como um estudo de caso num fornecedor automóvel de nível 1.

Palavras-chave

SMED, Máquina de feixe de electrões, irradiador, *Lean Manufacturing*, Setup

Abstract

Similar to the invention of the air plane, the emergence of automobile had a tremendous impact in our today lives. The innovation and the more sudden market fluctuation of the global market obliged to a quicker response to the supplier (independently of the tier), to be agile and give a quick answer to their client requests. Since that we can consider that the automotive industry is inserted in one of the most competitive market where the smallest modification in a setup is part of the solution to the success of the company.

New philosophies, such as Lean, with innovative methods and business models can be able to reduce costs and increase productivity, eliminating all non-value-added activities (wastes) through continuous improvement. Those philosophy should be implemented carefully since their failure can lead to tremendous loss who can be irreparable. Some characteristics are primordial, softs skills such as commitment, communication, skills and an open-mind to modify/erase/create activities and mindset are the root and the key to success.

The review done for this thesis shown that it already exists lot of SMED implementation program in automotive industry (where the tool born) but also in an important variety of industries. Anyway, not of them was done in electron beam machine (or irradiator) independently of his purpose (an irradiator can be used for a wide range of industry and services).

Succinctly, this project will be developed as a case study in a tier one automotive supplier.

Keywords

SMED, Electron beam machine, irradiator, Lean Manufacturing, Setup

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Acronyms List

PE	Poly ethylene
PLC	Programmable Logic Converter
5S	Seiri, Seiton, Seiso, Seiketsu, Shitsuke
VSM	Value Stream Mapping
TPS	Toyota Production System
TPM	Total Preventive Maintenance
SMED	Single Minute Exchange of Die
WWII	World War II
CEO	Chief Executive Officer
LM	Lean Manufacturing
ICT	Insulated Core Transformer
KV	Kilo-Volts
ISO	International Organization of Standardization
eV	Electron-Volt

Chapter 1

Introduction

1.1. Introduction

During the last twenty years, the global economic regime has become more and more liberal, while the focus in innovation is replacing the traditional business models oriented to the costs in many enterprises (Keupp et al., 2012). Beyond the omnipresent technological and product innovation, a series of new topics related to the innovation emerges such as organizational innovation, services innovation and process innovation (Mol et al., 2009).

Since the beginning of such precautions that automotive industry became the main case study to implement and create innovate management models. As example, TPS (Toyota Production System), created by Eiji Toyoda and Taiichi Ohno in the 50's, who was applied in Toyota focus on the elimination of different type of wastes (activities who does not add value for the product) and different techniques was developed such as production in small batches or stock abatement encourage that action with the purpose to reduce time set up, a push production capacitor, was primordial (Godinho Filho et al. 2004).

Lean Production concept has its origin in TPS where two main pillars can be considered, Automation (or *Jidoka* in Japanese) and Just-In-Time production. *Jidoka* corresponds to the productive equipment's capacity of stopping production whenever occurs an anomaly. JIT wants to produce only what is necessary, in the required quantity and at the right time (Monden, 1998) or, in a production approach, JIT have the purpose to soften and render sustainable the production and increase quality level but always according deadlines since that in automotive industry the penalties for non-compliance are extremely high.

The Lean production practices and tools have been commonly used to reach such objectives and to win competitive vantages over their direct concurrent (Belekoukias et al., 2014) and are now applied in other industries such as aeronautical (Jurado et al. 2011), textile (Moxham, 2001), furniture (Sabri et al., 2004) or even health-care (Fabbri, 2011).

Since Lean Manufacturing requires small batch sizes and high product variation a new method had to be developed to reduce the setup times.

1.2. Purpose

The main purpose of the project describe here is to related part of a project to increase productivity in electron beam machine who are used in Coficab Group, leader on automotive wire and cables production.

Due to spool capacity, different per cross-section and diameter, the operators are obliged to load new spools many time per shift. Since the number of new loads cannot be reduced, due to different kind of limitations, the setup-time and time preparation for the machine is crucial.

SMED methodology is the most common tool used in those situations and will be tested in two electron beam machine installed in Coficab Portugal.

The project described here will have in consideration several questions such as:

1. In any case that a step fail, the associated risks are known and controlled?
2. With today's technology the modification proposed can be implemented?
3. In case of software and/or hardware modification, the payback period is calculated?
4. The security for operator and machine remain the same as before?
5. All the persons (operators, different departments, plant manager) are involved in the process?

1.3. Methodology

A research can have the following macro objectives: familiarize with a phenomenon or achieve a new comprehension about it; presenting information's about a given situation, group or entity; verifying the frequency that an event occur or how is it connected with other phenomenon; verifying a hypothesis of casual relation between different variables (Selltiz et al., 1975). To achieve such objectives a research is developed around a long process who englobe different phases since the correct formulation of the problem until a satisfactory presentation of results, critical analysis and conclusions (Miguel, 2007).

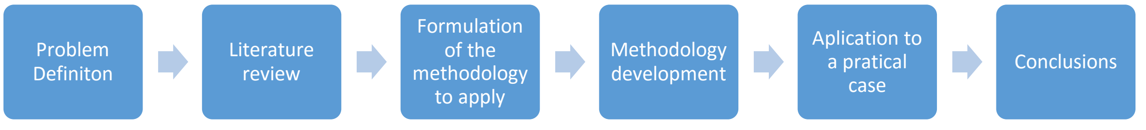


Figure 1 - Investigation Design (Adaptation from Kothari, 2004)

Case study is an empirical study who investigate a phenomenon, normally a contemporaneous one, in a real life context, when the frontiers between the phenomenon and the context where is insert are not clearly defined. It is an in-depth analysis of one or various objects (cases) who allow a vast and detailed knowledge (Nakano, 2000). The main purpose is to improve the knowledge in a problem who is not sufficiently defined (Mattar, 1996), it aim to stimulate the comprehension, providing hypothesis and questions or even develop the theory.

Voss (et. al, 2002) classified case study by their content and final purpose (exploratory, explanatory or descriptive) or quantity of cases (unique – holistic or incorporated in multiple cases – also categorized by holistic or incorporated). This classification assumes that single- and multiple-case studies reflect different design situations and that within these two types, there also can be a unitary or multiple units of analysis. (Yin, 2001) Independently of the type of case study, all types wants to clarify a decision or set of decisions: why they were taken, how they were implemented, and with what result. (Yin, 2001). In the point of view of Dangayach and Deshmukh (2001), case study should be classified in five major categories: conceptual (basic concepts of Lean Production (LP) articles), descriptive (explanation or description of LP and performance issues), empirical (qualitative approaches to collect primary data from existing database, case study and taxonomy approaches), exploratory cross sectional (requires data collection through surveys but the information gathered is at one point in time only) and exploratory longitudinal (where a data collection is done through surveys at two or more points over a period of time).

Methodologically, this paper is a discussion who result from an analysis of real situations in industrial environment and a literature review of Lean Manufacturing and SMED Methodology. However, this paper cannot be studied as a typical literature review but present some elements that can allow this classification, since one purpose is to identify, know and monitor the development of the research in this area.

Structurally this project will be based on SMED implementation methodology and model presented by Kusar (et. al., 2010), who have been tested in different companies by the author himself, where all steps to implement and control SMED improvement are clearly defined.

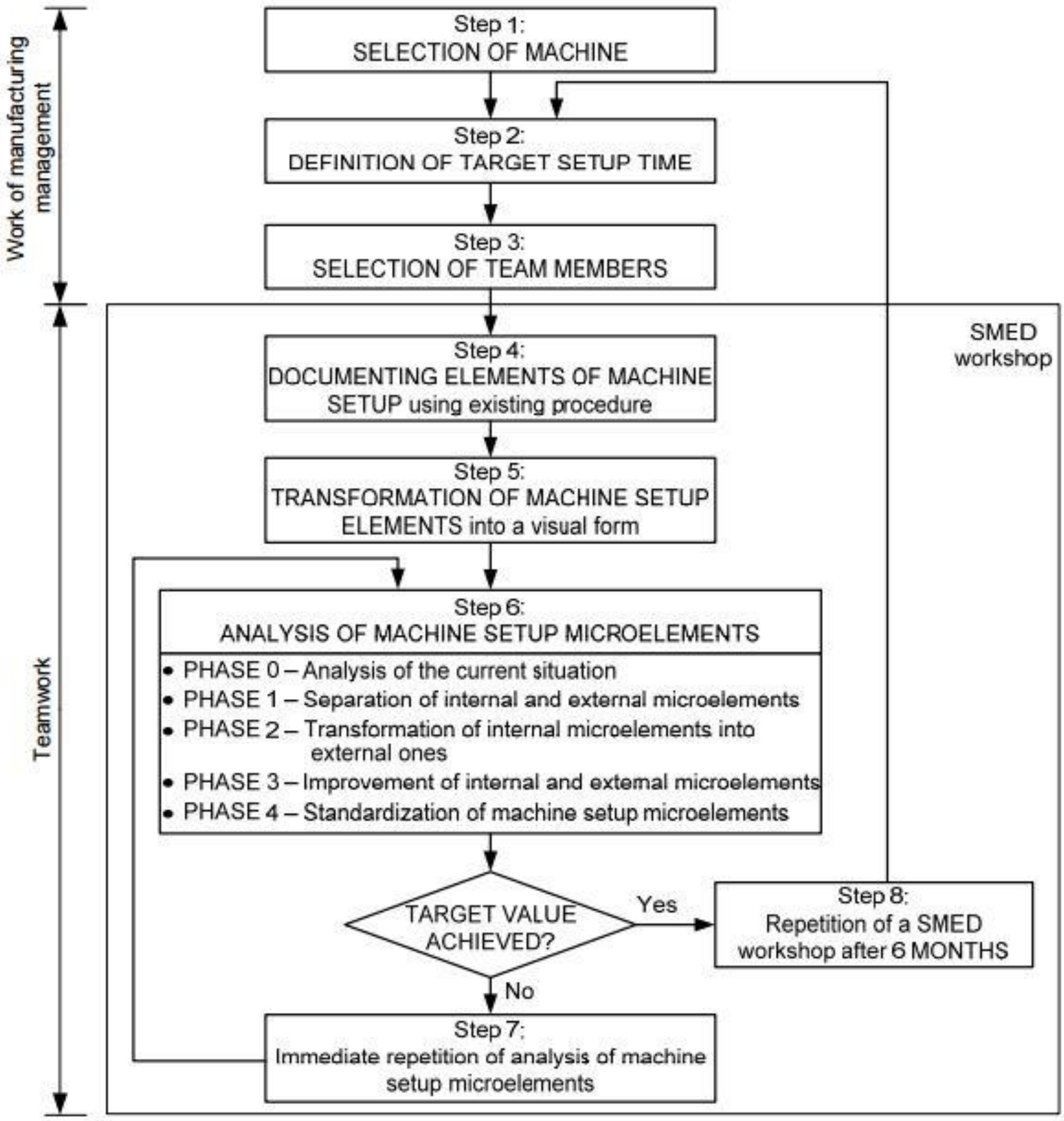


Figure 2 - Framework for organization and execution of SMED workshop (Kusar, et al., 2010)

1.4. Company Presentation

COFICAB core business is the manufacturing of electrical wires and cables for the automotive industry. It holds a leader position in this market with a share that exceeds 13% worldwide and approximately 50% in Europe. Coficab is also inserted in the energy industry.

Figure 3 - Clients and Homologations of Coficab (Coficab website)

Currently, Coficab is composed by ten plants. Three more plants are planned to open soon. The first plant was built in Tunisia (Tunis) in 1992 to supply the local demand. Throughout the last two decades, Coficab expanded globally by constructing up to date production facilities in 1993 in Portugal (Guarda), 2001 in Morocco (Tangier), 2006 in Romania (Arad) and recently (2009) in Tunisia (Medjez El Bab), 2012 in Morocco (Kenitra), 2013 in Mexico (Durango) and Romania (Ploiesti), 2014 China (Tianjin). The next plants integrating the group will be located in China (Beijing) and Serbia. The group also have Technical Centers in Tunisia, Portugal, Mexico and Germany.

The growth of the group had been driven by the undying concern to ensure to its partners outstanding services through performance in logistics, high quality products and innovation pipelines full of technological solutions and cost reduction programs.

Vision

To be the global and recognized leader on automotive wires and cables.

Mission

To give our best to our customers and partners and build a culture of excellence based on shared values, best practices and in full compliance with the legal and safety regulations.

To seek for sustainable growth, strive for innovation and invest in environment and human capital.

The project described was developed in the Portuguese plant of the group where three electron beam machine are installed, one in line with extruder machine and two considered offline, where the extruder are not coupled. Due to specific operation in the inline electron beam machine, the SMED methodology described here will be implemented in the offline machines.

1.5. Structure

Divided in five main chapters, this paper work will presented in chapter two a literature review about Lean Manufacturing and SMED Methodology where two generations of investigators will be presented. A fusion between ideas from Shingo Shingeo (inventor and first applier of SMED Methodology) and, for example, McIntosh will be demonstrated. Finding a commitment between the basis of the tools and a today point of view with all inherent innovation in their various application fields. Proving also the flexibility of such tool. Also the History of LM and SMED will be demonstrated, presenting their pioneers and the productivity, historical but also political reasons to justify such modifications who was, as we will see, difficult to accept.

Chapter three was developed with the main aim to demystify what is actually an electron beam machine, presenting the main components, objectives and process but, also how to handling wire (main product of Coficab) in it.

In chapter four, the company and also the different machines, and their various specificities, where the methodology is implemented will be announced.

Finally, in chapter five all the critics and final considerations regarding the results of the workshop will be discussed. Also, proposal for further workshops will be also shown.

Chapter 2

Literature review

2.1 Lean Manufacturing

2.1.1 Appearance

Industrial Revolution who began in the first middle of XVIIIth Century in United Kingdom brings new needs for Industry. Until there the manufacturing was centered in small shops who consequently with a reduced turnover and few clients. The producers, as we call nowadays as artisans, possesses the know-how of product and technologies applied in the epoch. Their approach to the final product began in raw materials until the delivery to the client. This kind of approach can guarantee a high quality of product but the productivity and occupancy of the different artisans was too elevated, who block higher productivity.

James Watt (Member of Lunar Society), present in all our History books, with his brand-new steam engine began to change this philosophy. The man-power was substituted by machines who reduced exponentially workforce with high availability. His will was limited since that the technology was not so evolved as today and the number of suppliers for this kind of equipment was short or even inexistent.

In XIX Century, Industrial Revolution became global, enterprises and industry with such a low productive capacity were trying desperately to fulfill client's requests with their high number of different demands. Henry Ford was the first entrepreneur who appear with terms such as "mass production" or even "series-assembly". This innovator develop the first line production in 1915 and with World War II many factories implement his model who still used nowadays not only in automotive industry but in almost all kind of industries.

After WWII and due to the huge necessity of rebuilding and restart normal life after the end of the War the industries starts to produce large amount of batches forgetting the high variety of products and negative effects of larges inventories who exists in productive lines (Riezebos *et al.,* 2009). The urge for an alternative to Ford Model appear and was primordial to fulfill the necessity of producing with a lower level of waste and a more flexible way to produce with high number of different products.

In parallel, Japan was devastated after WWII with no resources. CEO, Sakichi Toyoda, starts a weaving company and only after 30's decade he sells his patent to give the possibility for his son (Kiichiro Toyoda) to build an automotive industry to fulfil the Japan Government demand. Before the beginning of his new industry and attracted by mass production, which kept the western industries at high speed, he decided to go to USA to explore and learn Ford model but quickly he understood that such model cannot be applied in Japanese market since internal market was too small and Government was requesting an high amount of different vehicles, small (perfect to big cities), for authorities (Police, Ambulance, etc.) and trucks (agriculture and transports). Also, it is common knowledge that post world war Japan had:

- Higher raw material costs (Japan has few natural resources)
- Rigid salary ranges

Mass production followed the very simple equation of "quality equal to costs", and since the Japanese had the initial disadvantage of elevated costs, there was high risk of producing products of poorer quality than the western competitors.

The beginning of a new production system had begun. Toyota Production System was dawn by Eiji Toyoda but new concepts and improvements was done by Taiichi Ohno and Shigeo Shingo.

2.1.2. Proclamation of Toyota Production System

In the first years of the 1970s, the Gross Domestic Product [1]of the industrialized western nations was still increasing steadily, and with them, the purchasing power of the consumers. It has been sociologically proven that an increase of purchasing power is accompanied by an inevitable tendency of the consumer to demand higher quality, seen as reliability, personalized products and other bonuses. (Andrea Chiarini, 2013)

Japanese industry, especially Toyota, start to compete in the early years of the 70's decade with western industries since strategies and methods for improve production had been implemented to respond to customers' demands and to eliminate wastes regarding always the quality of their products and remaining with a competitive price.

Less than ten years after, Japan was seen as an example in industrial and economic contexts and the decline of western industries was clear and predictable. The response of those industry was not fast as should be due to philosophy and social contexts but had always TPS as a model that can be molded and modified dependently of industry, market and geography.

[1] Monetary value of all the finished goods and services produced within a country borders in a specific time period.

2.1.3. Lean Manufacturing

Taiichi Ohno, in 50's, began the creation and implementation of a production system which main goal was the identification and subsequent elimination of wastes with the purpose of reducing costs, time delivery to client/customer and increase quality of products.

James P. Womack and Daniel T. Jones, in 1990 their book *The Machine that changed the World,* called TPS as Lean Manufacturing since it is a way to produce more with less: less human effort, less equipment, less time, less space fulfilling more efficiently customers/clients wishes.

Lean Manufacturing appear as a necessity to adapt TPS to the quest/demand of the consumers/clients, who want several different and specific products with high standards of quality. The reduction of operational costs who permit to remain competitive against concurrence can be seen as a goal to Lean Manufacturing too. Such approach should be done in a transversal way, since raw-material supply until delivery to customer and should not be assume as an isolated process improvement.

As seen before, TPS revolutionize automotive industry and his success transform it into an highly efficient productive system regarding waste elimination and production flexibility but always focused in product quality (Braglia, et. Al., 2006). Such quality should be assume in very different level or ways. For example:

- Selling: Competitive price with competitors;
- Logistics: Delivery on time without any major problems;
- Human resources: All persons should be involved in process;
- Production: To produce different kind of products with high efficiency level.

Such approach as elimination of excess or fatness is supported by the integration of several tools and methodologies, based in a culture of refinement/enhancement constant and continuous improvement (Cabrita, 2009).

2.1.4. Lean Manufacturing principles

Dennis (2007) establish differences in a philosophical way between *conventional* production system and Lean Manufacturing.

CONVENTIONAL	LEAN MANUFACTURING
KEEP THIS RUNNING! MEET PRODUCTION OBJECTIVES!!	Stop production to not stop production (Jidoka – Quality)
PRODUCE THE MAXIMUM AS POSSIBLE, AND FAST AS POSSIBLE (PUSH SYSTEM)	Produce only what customer need (Pull system)
BIG BATCHES AND SLOW MOVES BY THE SYSTEM (BATCHES AND WAITS)	Producing one item and moving it as fast as possible (flux)
LEADER = BOSS	Leader = Teacher
THEY EXIST SOME STANDARDS BUT I DON'T KNOW THEM…	Simples standards and visuals for all important questions
SPECIALISTS CREATE STANDARDS. THE OTHERS ONE APPLIED THEM.	Persons involved in field develop standards and ask for help to specialists, when necessary
PROBLEMS ARE HIDDEN	Problems are shown
NO TRADITION TO GO TO THE LINE PRODUCTION	See problems in the site
DO - DO - DO - DO	Plan – Do – Check – Act (PDCA tool)

Table 1 - Conventional and Lean Manufacturing philosophy differences (Dennis, 2007)

Cristina Werkema (2012) identified five topics as fundamentals for Lean Thinking:

- Specify value (What customer need)

The definition of value should be the first point to consider, this point should defined by customer and never by the producer. For customer, the need will automatically generate value and it is to the producer to calculate the necessity, satisfied it and receive a specific price for maintain his company in business and increase profit via process improvement or reducing cost. Understanding what a customer valorize help any enterprise to reach what the client need in a way to valorize his own product/service (Hines et al., 2010)

- Identify stream value

Dissect supply chain and separate different processes in three phases: which one of really increase the value, the others who don't increase value but are important for maintenance of the processes and/or quality of product and finally the processes who don't aggregate value to the final product (and need to be eliminated as soon as possible).

- Create continuous flux

A change of mentality is vital in this phase since the flux identified in the previous should be evaluated. The idea of production per department should be avoided. The effect of such modifications can be verified almost instantly in time production and time for processing clients requests. Stocks should be reduced too. The capacity to develop, produce and deploy as quickly as possible can give to a company a short time of response for their customers. The reduction of time, handling requests and inventories too are immediate results of the introduction of this principle, letting the industries with a more efficient feedback to the necessities of the market (Pinto, 2008)

- Pull system of production

This flux can invert normal flux production: The industries will no longer "force" their client to accept their products. The customers will start to ask (or pull) the products to himself.

- Finding perfection

Perfection should be a constant goal in all people's presents in the flux of value. This quest should guide all efforts in the company where all persons involved have a strong knowledge about different processes who can allow anyone to dialog and find best practices in all stages.

For Pinto (2008), such principles are considered nowadays as incomplete. For the author, it is fundamental to add two more principles to put any company in the way of excellence:

- Knowing stakeholders

We need to know all details about all stakeholder in the business, focus all attention in final client and not only in the next client in the value chain.

- Innovate always

Innovate to create new products, new services, new processes, or for least but not last: add value.

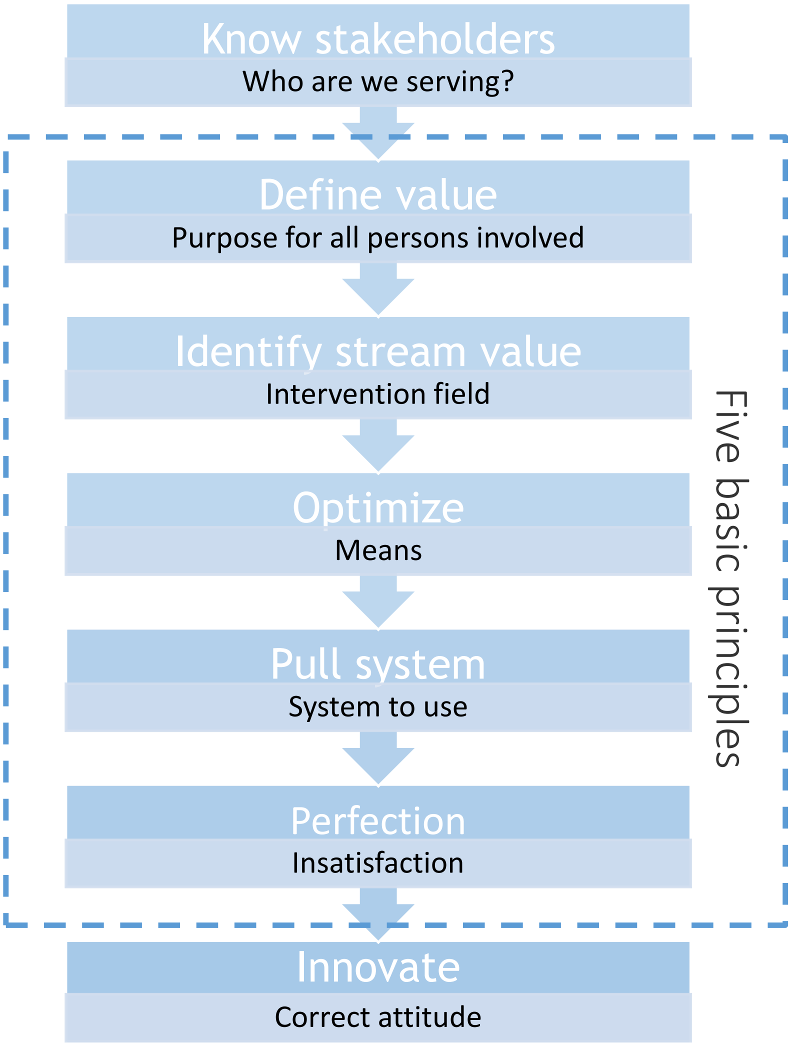


Figure 4 - Adaptation of the seven Lean Manufacturing Principles (Pinto, 2008)

2.1.5. Type of wastes

"There is nothing more useless then doing something efficiently what should never be done. " (Drucker, 1980)

Ohno (1988) defined as waste, or muda in Japanese, all elements from production who only increase cost or time production without aggregating any value for product, in other words, activities that don't add value to product in the point of view of the client but are realized in the production process. Shingo (1981) identify seven kind of waste in Lean Manufacturing. They are:

- Over production: When the production is done too soon or when is not necessary. As result, the stock increase and production line is not available for product which are really necessary. The risk of obsolete product increase too.
- Wait: Idleness of persons, parts or information's who result in poor flux and long lead-times.
- Transportation: High amount of transport of product (non-finished or finished) information or parts or even inappropriate working environment. This type of waste can result in waste of capital, time and energy;
- Motion: Working environment inappropriate, low ergonomics, wrong or unavailable tools arrangement, systems or procedures who can result in lower productivity level;
- Unnecessary inventory: Excessive storage and lack of information and/or products. This waste is directly linked with provided services to customer;
- Defect: All activities related with inspection or reparation who can affect the product quality;
- Over processing: All efforts done that don't add extra value to the product, in the client perspective. This type of waste can include extra inspection, incorrect transformation.

Liker (2005) identify a new type of waste. The under exploitation of people, specifically their formation, ideas and creativity. To achieve the success in a company all members should be involved.

Lean philosophy classified also the type of operation. The one that "add value" and the one that "don't add value" to the product. Operations that add value to the product/customer can be also distinguished as "necessary" and "unnecessary". Operations that don't add value and are unnecessary should be eliminated avoiding unfinished or unprepared products for the customers or even chaos in the production line (Leite, 2008)

But Lean Manufacturing can be considered the 3M philosophy since it is mainly focus on muda or waste, muri or unreasonableness who is the irrationality for per excess or lack, as example, the lack of formation/knowledge of a new operator in his workplace can cause a high amount of errors (Imai, 1997) or blaming other people instead of looking for a real and concrete resolution for a problem (Womack, 1990) and mura or inconsistency who are problems that increases the variability of manufacturing. (Womack, 1990).

"The inevitable result is that Mura creates Muri that undercuts previous efforts to eliminate Muda." (Womack, 2006)

As Womack said in 1990, in most companies we still see the Mura of trying to “make the numbers” at the end of reporting periods. (Which are themselves completely arbitrary batches of time.) This causes sales to write too many orders toward the end of the period and production mangers to go too fast in trying to fill them, leaving undone the routine tasks necessary to sustain long-term performance. This wave of orders -- causing equipment and employees to work too hard as the finish line approaches -- creates the “overburden” of Muri. This in turn leads to downtime, mistakes, and backflows – the Muda of waiting, correction, and conveyance.

2.1.6. Methodologies and tools

Most organizations begin by implementing Lean techniques already known in a particular production area or at a “pilot” facility, and then expand use of the methods over time. Companies typically tailor these methods to address their own unique needs and circumstances, although the methods generally remain similar (Ross and Associated Environmental Consulting, 2003).

The concept of Lean is not only restricted to automobile industry (where it appear for the first time) but it is applicable to almost all the industries (Crute et al. 2003). Now it has spread over all the vertical markets such as chemicals, aerospace, electronics in manufacturing sector and across various other sectors like service sector (Bowen and Youngdahl 1998; Atkinson 2004; Abdi, Shavarini, and Hoseini 2006). Due that new techniques and tools are created and developed every day for specific area of implementation but according Silva (2011), the most remarkable and used techniques for Lean application are:

- Value Stream Mapping: Diagnosis tool who purpose a representative diagram who represent all activities in process, materials and information flow during all chain value of a product. The main purpose of this diagram is to have a vision of the global chain value of a product, identifying activities that aggregate value, associated sources of wastes and with that, develop better practices. Rother and Shook (2003) divided VPM in four steps as shown in next figure.

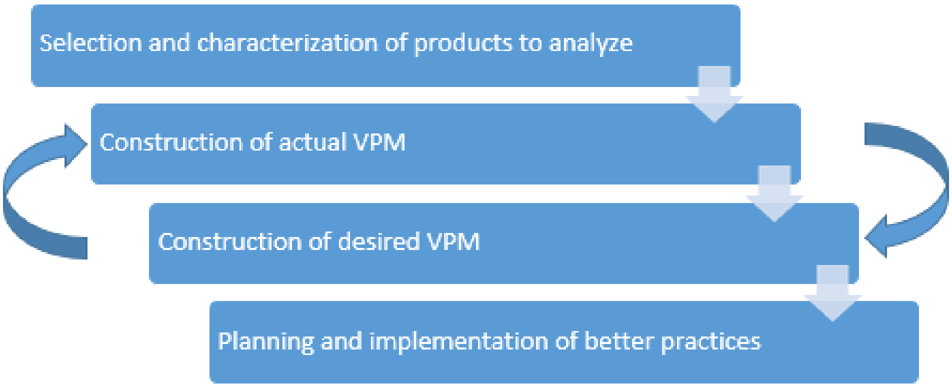


Figure 5 - Adaptation of the four steps of VPM (Rother & Shook, 1999)

- 5S: 5s terminology emerge from five Japanese words who are the bases of this method. Seiri – Sorting – Verification of materials, tools and equipment in the correct place in determined work space removing all unnecessary equipment. Seiton/ – Straighten – Organize all material, tools, and spaces in a way that everything can be always reachable as quick as possible. Seiso – Sweeping – cleaning all areas, equipment's and tools with intuit to turn everything visible, reachable and arranged. Seiketsu – Standardizing – Use the same disposition, visual control and tools in all areas to expedite turnover between operators. Shitsuke – Sustaining – Sustaining and review all modifications done with the intention of practicing better practices. Such philosophy evolved directly with people in a way to find better condition in terms of organization of their own work spaces through activities rationalization, eventual progressive changes in team works, giving a dynamic environment, trying to agile operators turning themselves into operators multitasking and connoisseurs in all areas, allowing a large comprehension in all production line, (Ross, 2003). Team involved in 5s implementation should answer as maximum as possible the operators who want to turn their own work space more comfortable and effective (Bertholey et al., 2009).

- Heijunka: Term used to describe a mixed production system where various and changeable sequence of mixed models are produced on the same assembly line. It is consistent with the well-organized Toyota notion that "production must be viewed as something that naturally and faithfully conforms to firm orders" and reflects the Toyota mind-set against speculative production and the ideas that market fluctuations must create inventories (Coleman, 1994)

- Poka-yoke: Simple devices, who can stop current operation or process when the probability of defect increase drastically or actually occur. Poka-yoke devices have a huge contribution to auto-nomination, turning process control more autonomous. (Shingo, 1986);

- Kanban: The main purpose of Kanban is to control stocks, production and supply of components cooperating with JIT (Júnior et al., 2010). Kanban prevent high level of stocks, contributing in an equilibrium between stocks and client requests (Chan, 2001). This technic allow the production of a new piece in a determined work shop step only when this one receive a signal in the next process who inform himself that he need the supply of a new piece to not stop his own production.

- Kaizen: Lean is founded on the idea of continuous improvement (Kaizen, in Japanese). Such philosophy implies that small changes routinely applied and sustained over a long period will result in significant improvements. Kaizen focuses on eliminating waste in the targeted systems and processes of an organization, improving productivity, and achieving sustained continual improvement.

- Standard work: Best combination of resources such as operators, machines, tools and metrology. To secure that a task is done always in the same way (Perrin, 2005);

- TPM: Organize the Maintenance function with the main purpose to increase effectivity (efficiency and effectiveness) in the utilization of equipment's. With the support of best practices and technology improvement such as autonomous maintenance or planned one (Nakajima, 1989);

- SMED: Developed by Shingeo Shingo in 1985, he defined SMED as a scientific approach to reduce setup, who can be applied in any factory or equipment. As setup we can consider all activities of preparation for a machine to change the product produced in batch must be switch and the time between such changes motivate higher batches. (Shingo, 2003)

2.1.7. Implementation

In the last years, the number of companies who are practicing Lean Manufacturing is increasing in all industrial and services sectors. Anyway, is important to highlight that LM adoption represent a process of modifications of organizational culture and, for that reason, is not easy to reach. The fact that a company is using Lean tools does not mean that total success was reach in implementation (Werkema, 2012)

Lean implementation have an important contribution for a strong and sustainable growth in efficiency of a plant, increasing their productive capacity and giving, as a result, a better response to customers demands, an high flexibility to respond to them too, maintaining always minimum stocks, without defects and with an excellent quality rate (Arbós, 2008).

2.2. SMED Methodology

As explain in the previous chapter, SMED method is one of LM methods or tools which allow successful competition in domestic and foreign markets (Kusar, et al., 2010)

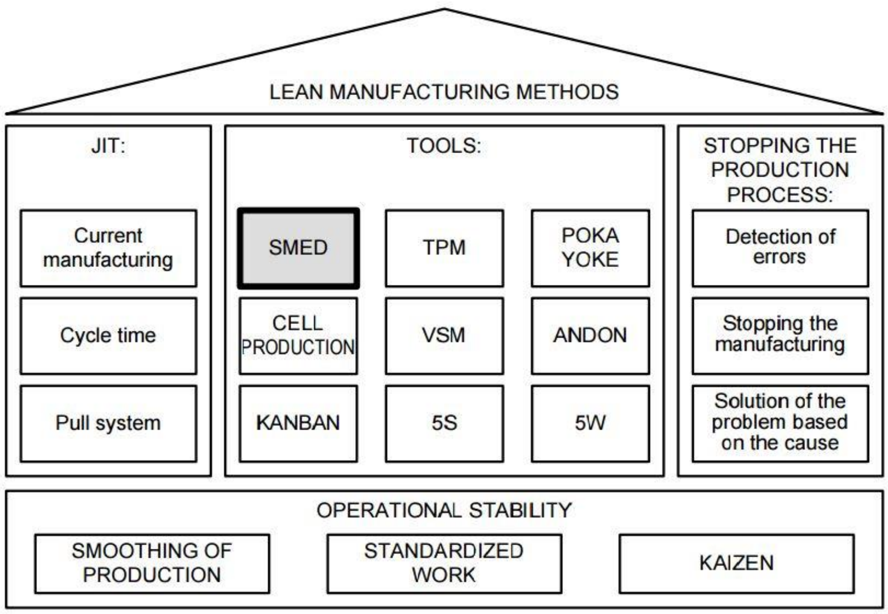


Figure 6 - Lean Manufacturing methods and tools (Kusar, et al., 2010)

SMED was published for the first time in 1985 in Orient (Womack & Jones, 1998). Identified as a tool genuinely Japanese, it will be also a concept very regular who will be spread in Industrial Engineering all over the world (Cusumano, 1989). Since many articles and cases study refers and use SMED to reduce time set-up, this methodology is the main tool to use when the purpose is to reduce time set-up.

2.2.1. Appearance

All techniques applied by Toyota was developed internally, excluding SMED who was developed by Shigeo Shingo (Womack & Jones, 1998). Shingo took nineteen years, as the proper said in his publication SMED – Revolution in Manufacturing, to reach his culmination of ever-deepening insight into the practical and theoretical aspects of setup improvement. The development of

SMED was focused to reduce set up time on a 1,000 ton press who took few hours and, after development, took ninety minutes. This press was installed in Mazda's plant in Hiroshima.

2.2.2. Definitions

Since SMED focus in reducing set-up time, the concept of set-up should be clear as possible.

Shingo (1985) defined set-up as an application of much more than the preparation and after-adjustment of a processing operation; it also refers to inspection, transportation and waiting operations. Consequently, the approach — that is, the conceptual stages, corresponding methods, and specific techniques for improving setups — can be applied in precisely the same way to all operations. In another way, Juan A. Marin-Garcia and Tomas Bonavia, consider SMED as a practice would attempt to reduce the time and costs involved in changing from the tooling, layout, etc. required to produce one product to that required to produce other products. But according McIntosh (et. Al, 2000) setup period is only part of a switch between two references. For the writer, set-up should englobe period between the last piece of previous reference and the first piece of the new reference with a correct quality index and a correct productivity performance.

McIntosh et al. (2000) also defined SMED as three different distinction: SMED as a concept, SMED as a methodology or SMED as improvement program.

Concept: SMED should be understand as an enouncement of the conceptual stages in a way to reduce setup time or preparation time with defined objectives and a specific application;

Methodology: With four different conceptual stages (defined by Shingo, 1985) in a flowchart who can allow to reach a pre-proposal aim.

Improvement program: With a continuous improvement thinking, the working method can be brush up. In this case, improvements can be applied in different ways (process or equipment's), responsibilities can be formalized and teams can be formed to agile the improvement.

2.2.3. SMED thinking

The economic benefits derived from SMED implementation are not always the same and depend on the machine arrangement to which the SMED is applied.

In some cases, the machine on which the methodology is applied is saturated. If the objective of the SMED is to liberate the machine from its load time to increase machine availability, the benefit takes place because of the economic margin in the sales increment.

It seems logical that one should know what operations should be conducted while the machine is still processing the previous lot. Unfortunately, much time wasting takes place in many setup processes. For instance:

- Materials are moved to the warehouse with the machine stopped.
- Tools and dies are supplied late or incorrectly.
- Tools and dies that are not needed are taken back to the supply room before starting the machine.
- Some needed screws and tools were not collected during the setup process.
- Some nuts are just too tight when one attempts to remove them.

It is necessary to eliminate all these wastes before starting the setup. Some good questions to ask include:

- What has to be done before starting the change?
- How many screws are necessary to fix the die? Of what type?
- What tools are necessary? Are they prepared properly?
- Where the tools should be placed after using them?

2.2.4. Impact

Beside time reduction, as shown in Figure 2, Shingo identified that SMED methodology have other knowns and benefic impacts in production.

COMPANY	CAPACITY (IN TONS)	BEFORE IMPROVEMENT	AFTER IMPROVEMENT
K AUTO	500 t – 3 Machines	1 hr. 20 min	4 min 51 sec
S AUTO	300 t – 3 Machines	1 hr. 40 min	7 min 36 sec
D AUTO	150 t	1 hr. 30 min	8 min 24 sec
M ELECTRIC		1 hr. 20 min	5 min 45 sec
A AUTO BODY	150 t	1 hr. 40 min	7 min 46 sec
K INDUSTRIES	100 t	1 hr. 30 min	3 min 20 sec
S METALS		40 min	2 min 26 sec
A STEEL	100 t	30 min	2 min 41 sec
K PRESS		40 min	2 min 48 sec
T MANUFACTURING	80 t	4 hr.	4 min 18 sec
M IRONWORKS		50 min	3 min 16 sec
H ENGINEERING	50 t	40 min	2 min 40 sec
M ELECTRIC		40 min	1 min 30 sec
H PRESS	30 t	50 min	48 sec
K METALS		40 min	2 min 40 sec
Y INDUSTRIES		30 min	2 min 27 sec
I METALS		50 min	2 min 48 sec

Table 2 - Time reductions achieved by Shingeo Shingo experimentation, (Shingo, 1985)

- Stockless Production

It is true, of course, that inventories disappear when high-diversity, and low-volume orders are dealt with by means of high-diversity, small-lot production. Yet the multiplicative effects of the high-diversity component, on the one hand, and the small-lot component, on the other, lead inevitably to a substantial increase in the number of setup operations that must be performed. Cutting setups that used to take two hours to three minutes with SMED, however, changes the situation considerably. The SMED system offers the only path to both high-diversity, small-lot production and minimal inventory levels.

Moreover, when a system of production that minimizes inventories is adopted, the following collateral effects can be expected:

- Capital turnover rates increase;
- Stock reductions lead to more efficient use of plant space;
- Productivity rises as stock handling operations are eliminated;
- Unusable stock arising from model changeovers or mistaken estimates of demand is eliminated;
- Goods are no longer lost through deterioration;
- The ability to mix production of various types of goods leads to further inventory reductions.

- Increased Machine Work Rates and Productive Capacity: If setup times are drastically reduced, then the work rates of machines will increase and productivity will rise in spite of ail increased number of setup operations;
- Elimination of Setup Errors: Setup errors are reduced, and the elimination of trial runs lowers the incidence of defects;
- Improved Quality: Quality also improves, since operating conditions are regulated in advance;
- Increased Safety: Simpler setups result in safer operations;
- Simplified Housekeeping: Standardization reduces the number of tools required, and those that are still needed are organized more functionally;
- Decreased Setup Time: The total amount of setup time — including both internal and external setup — is reduced, with a consequent drop in man-hours;
- Lower Expense: Implementing SMED increases investment efficiency by making possible dramatic increases in productivity at relatively little cost. The cost of setups for small, single-shot metal press dies runs about ¥30,000-¥50,000 ($124-$206) in Japan and is about the same for plastic molding machine dies;

Goubergen & Landeghem (2002) classify the different reasons for reducing setup time into three main groups:

- Flexibility: Due to the large amount and variety of product and due to the reduction of the quantities requested by customers, a company must be prepared to quickly react to customer's needs.
- Bottlenecks capacity: Especially in these cases, every minute lost is crucial. Setups should be minimized to maximize the available capacity for production.
- Costs minimization: Production costs are directly related to the equipment's performance. With the setup time reduction, machines stop during less minutes, thus reducing production costs.

Pablo Guzmán Ferradás & Konstantinos Salonitis (2013) show us that The Economic Order Quantity (EOQ) model can explain how SMED can help reduce cost by lot size reduction, as shown in figure XX. EOQ is defined as the lot size that minimizes total annual cycle-inventory holding and ordering costs. In a production environment, total inventory costs are related with holding work or keeping items on hand (storage, insurance, handling, etc.). Ordering costs are related with equipment efficiency, being affected directly by changeovers due to time loses.

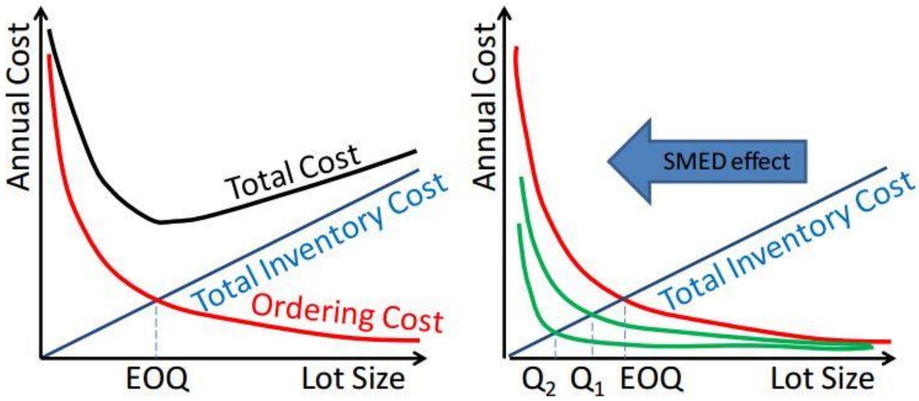


Figure 7 - Economic Order Quantity and SMED effect on reducing ordering cost (Adaptation of Ferradás & Salonitis, 2013)

2.2.5. Extension of SMED

The conventional definition of setup is “the time between the production of A product to B product with quality”, but as said before, McIntosh (ET. Al, 2000) define that setup should englobe also run-down (last piece of previous reference) and run-up (first piece of the new reference with a correct quality index and a correct productivity performance). Some authors recognize that the recuperation of productive capacity is not reestablish right after the end of the setup activities and neither after the production of the first good piece of the next batch (McIntosh et al., 2001). Same approach can be applied during run-down, where loss of production occur, though is inconspicuous sometimes.

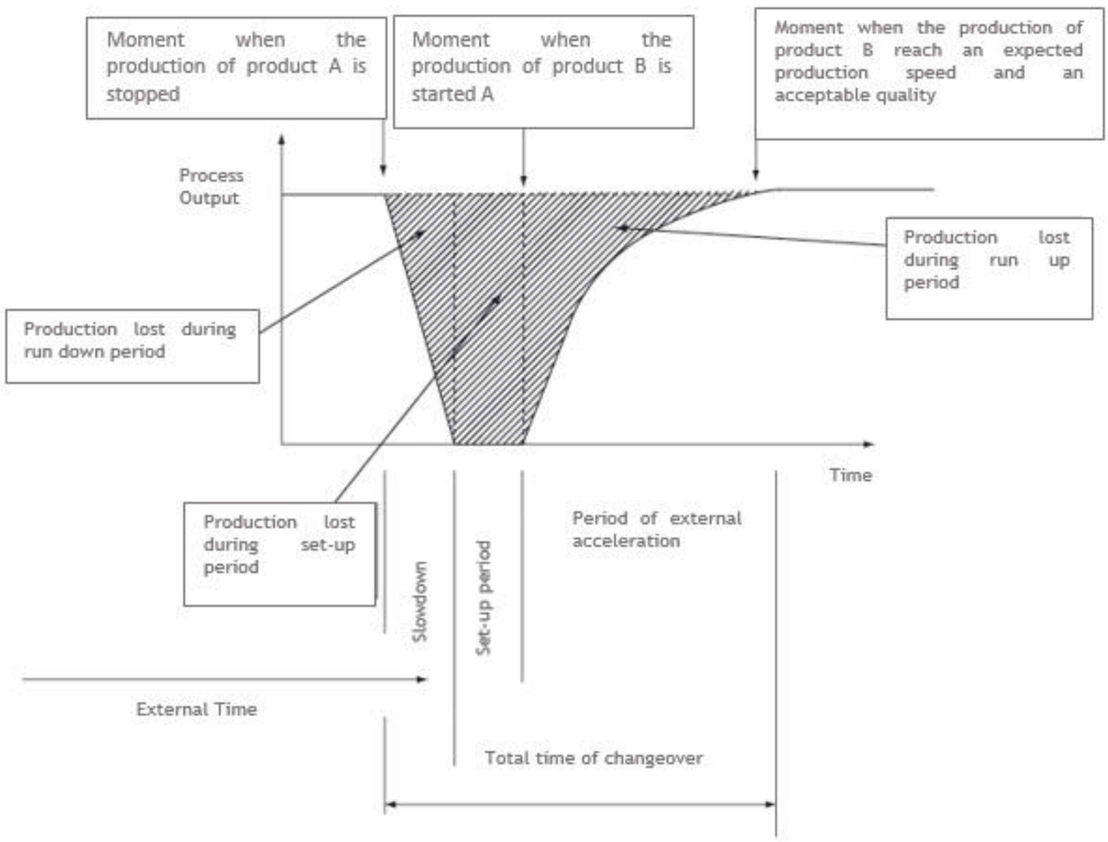


Figure 8 - Production losses during run-up and run-down period (Adaptation from McInsosh, et. al., 2001)

2.2.6. Different stages of application

Shingo (1985) identified three main steps to implement SMED. The first one occur in Mazda Toyo Kogyo in 50's. During the analysis performed to eliminate bottlenecks caused by large body-molding presses Shingo classified as intern setup all the activities performed when the machine is stopped and extern setup as the activities done when the machine is running.

Second step, in Mitsubishi Heavy Industries, who occur in the late 50's, the duplication of tools who allows that setup was done separately increase the productivity in 40% (Miguel Sugai, et. Al., 2007).

The last step occur in Toyota Motor company in 1969 where the setup for a 1000 tons press demand four hours of works versus two hours that a similar press demand in competitors such as Volkswagen company. Shingo reduces the setup to three minutes (Shingo, 1985).

Shingo (1985) establish four conceptual stages (preliminary, first, second and third stages) and develop several techniques per stage.

In the preliminary stage, internal and external setups are not identified. Initially internal and external activities are not distinguished and are performed by the operator in a random order. (Silvia Pellegrini, et al., 2012).

The first stage consists on separating the operations that should be carried out when the machine is still processing the previous lot (external setup) and those where it is necessary to carry out setup with the machine stopped (internal setup). This classification takes into account the same operations and duration included in the current method, i.e., without improving any particular operation (Javier Santos, et al., 2006).

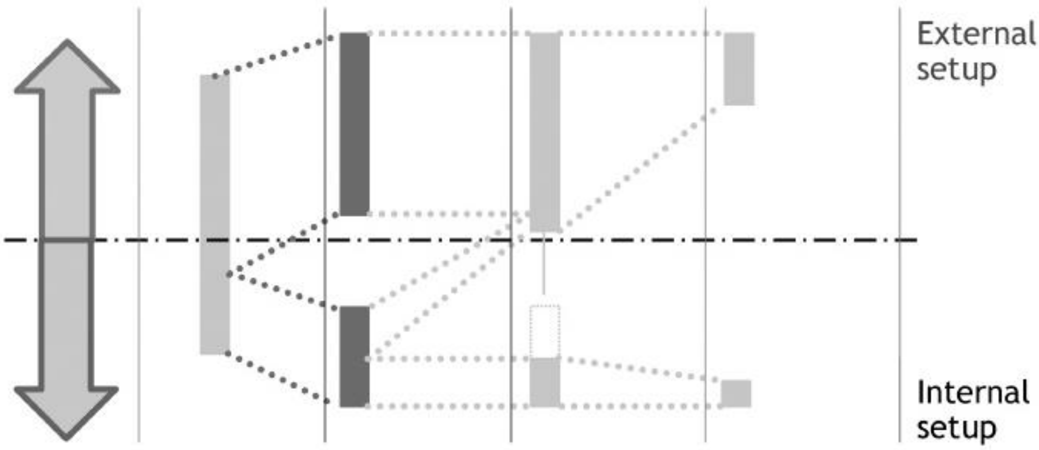


Figure 9 - SMED first stage (Javier Santos, et al., 2006)

The stage two has as main purpose converting internal setup as external. To convert internal activities into external activities, one should look at setup as if it was the first time, questioning the true function and purpose of each operation. Advance preparation of operating conditions, function standardization and intermediary jigs can be used to convert internal activities to external ones (Silvia Pellegrini, et al., 2012).

Javier Santos (et. Al., 2006) identified two important aspects of the operation in the second stage:

- Reevaluate the internal setup operations to check to see if some of them were considered internal erroneously.

- Look for alternatives that allow internal setup to be carried out in whole or in part as external operations, with the machine working. For example, is it possible to screw a die to a press before placing it inside the press chamber? The answer is yes.

In order to decide on an alternative's viability, it is necessary not only to analyze the economics but also to study the new process or system reliability, i.e., the possible appearance of new operations (both internal and external) that increase the setup time and, of course, the benefits and possible risks of the new process

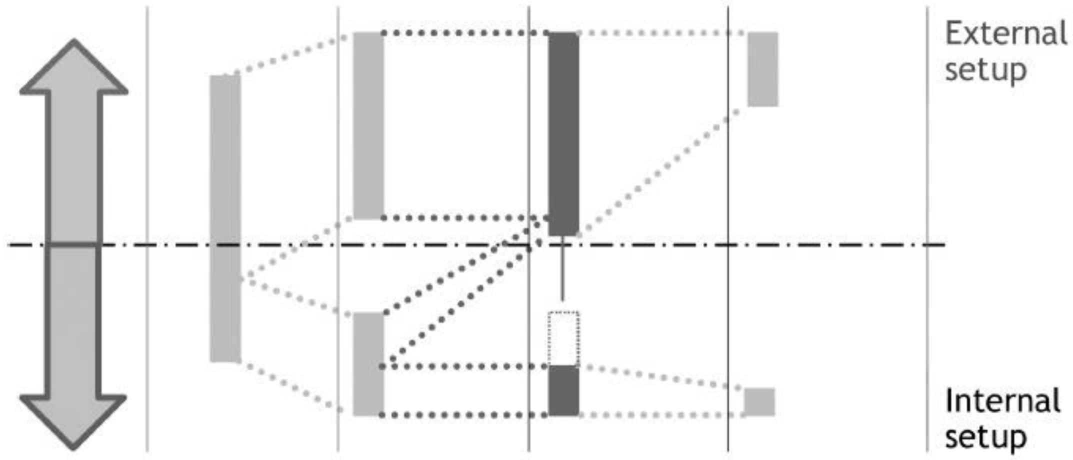


Figure 10 - SMED second stage (Javier Santos, et. al., 2006)

At last, stage 3 will streamline all aspects of the setup operations, reducing the duration of the setup operations (either external or internal) or even, if possible, trying to eliminate some operations. Adjustments can account for up to 50 % of the overall setup time in a traditional setup creating opportunities for great savings (Silvia Pellegrini, et al., 2012).

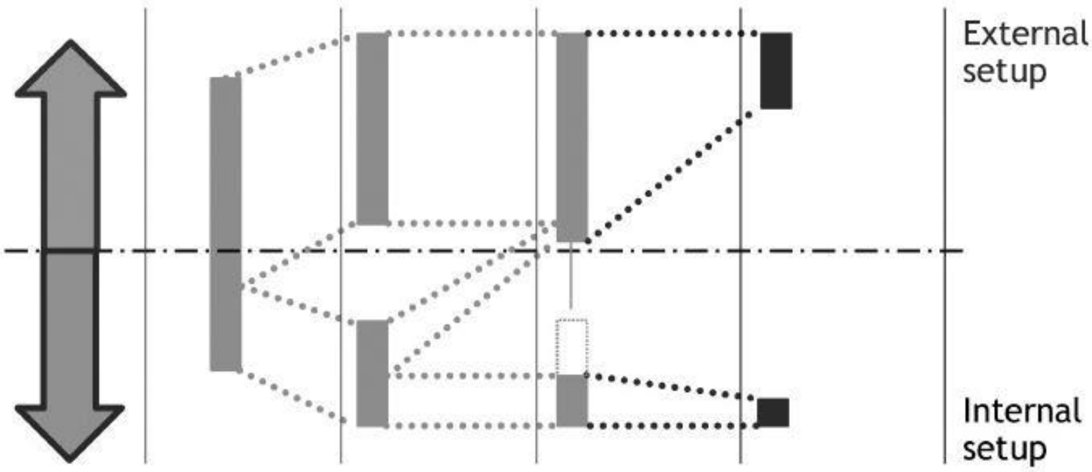


Figure 11 - SMED third stage (Javier Santos, et al., 2006)

McIntosh et al. (2000) said that Shingo methodology find, a priori, organizational improvements in stage one and two to do modifications in course who are possible in stage three.

2.2.7. Tools and techniques

For a correct and truly benefic implementation of SMED methodology some tools has been developed or modified per stage of implementation, such tools are described by Javier Santos (et al., 2006) and Shingo (1985):

- Stage one
  - Checklist: This tool consists of a questionnaire that should be checked before each setup process. The goal of the checklist is to verify in advance that all elements that should be prepared before the machine finishes the current lot are in fact ready and available. The checklist can be universal for all product changeovers or specific for each product. In the first case it will be placed near the machine, whereas in the second case it will be enclosed with the manufacturing order;
  - Function Checks: The checklist or the check panel do not show the die and tools status. Some plastic injection molds have material inlays that should be cleaned. If they are discovered in the trial step, cleaning of the mold can be carried out before the machine is stopped.

- Part and Tool Transportation Improvements: Part and tool transportation from the warehouse to the work area should be carried out before the exchange begins.

- Stage two
    - Preparing Operating conditions in advance: The first step in converting setup operations is to prepare operating conditions beforehand (Shingo, 1985);
    - Function Standardization: Only the most important components for the exchange will be standardized, taking into account two main conditions:
        - The setup process should be as safe as before.
        - The quality of the manufactured pieces should not be adversely affected.

Sometimes, when standardizing a particular measure, it will be necessary to develop a new device. This can be the right time to add new functionalities. In many cases, it will not be possible to standardize all the machine tooling owing to the large number of different tools used. Nevertheless, developing constraints and restrictions to use for the specification of future tooling, coupled with standardization of the most used tooling, can be very beneficial.

- Intermediary jig: In the processing of many items, two standardized jig plates of the appropriate size and shape can be made. While the workpiece attached to one of the plates is being processed, the next workpiece is centered and attached to the other jig as an external setup procedure. When the first workpiece is finished, this second jig, together with the attached workpiece, is mounted on the machine. (Shingo, 1985)

- Stage three
    - Improving storage and transportations of tools: It is necessary to study the workload of the setup specialists and to schedule the changeovers so that the specialists are not needed at the same time on two different machines; otherwise, the work carried out to improve the setup time will be pointless.

At this point, we should consider if the collaborator have enough time to organize the material and tooling and also carry out all the external operations. It is necessary to study the workload of the operator and schedule the changeovers so that he is not needed at the same time on two different machines; otherwise, the work carried out to improve the setup time will be pointless.

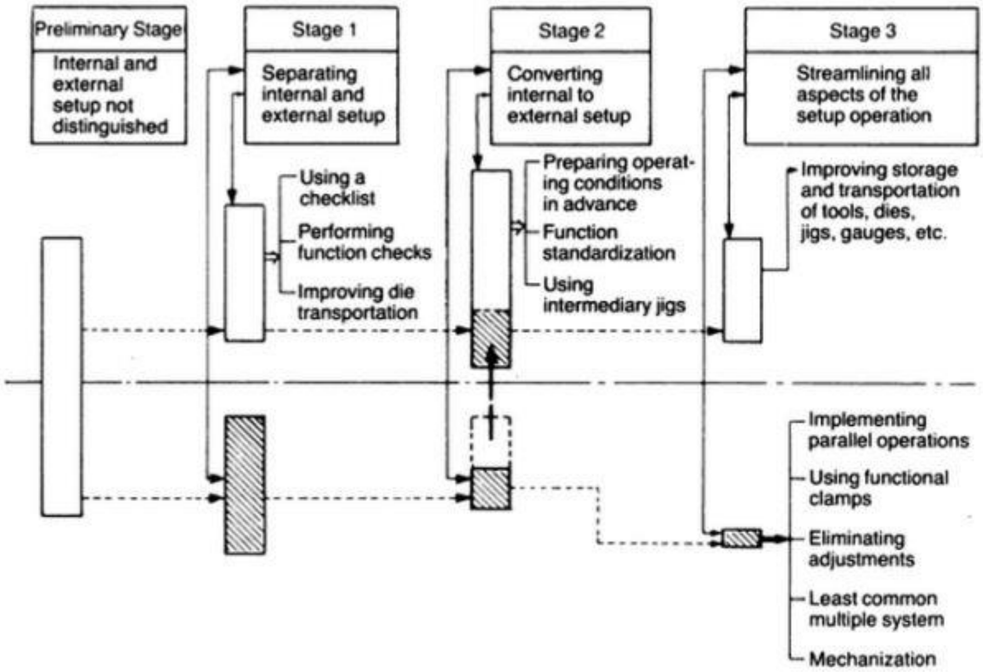


Figure 12 - SMED Conceptual stages and Practical techniques (Shingo, 2000)

2.2.8. Implementation Failure

It is important to define what success and what failure is on SMED implementations. Some researchers suggest that with SMED it is easy to achieve reductions of up to 90% (Van Goubergen et al., 2002). However the literature review has not resulted in any descriptive examples proving these ambitious results from real implementation cases (P. Guzmán Ferradás and K. Salonitis, 2013).

Although SMED is known for more than twenty five years and many examples are reported on successful initiatives, a number of companies have failed on implementation. Few studies have been presented on failing initiatives and the causes of such failures. McIntosh et al. (2000) argue that one possible cause might be the strictly application of SMED of methodology. The four stages pathway might not be the most efficient way to reduce set-up times in all situations. Indicatively, some companies put too much emphasis on transferring changeover internal tasks to external, missing the importance of minimizing or streamlining internal and external activities by design improvements (P. Guzmán Ferradás and K. Salonitis, 2013).

Also, an important changeover aspect, the run-up period, has been given little attention. McIntosh et al. (2000) defines the run-up period as the time when steady state manufacture is being re-established, with optimal productivity and quality rates. SMED methodology does not cover the run-up period as part of the changeover reduction strategy.

Another shortcoming of SMED method, lies with the fact that it addresses set-ups performed by one operator involving one single machine, when, in practice, there is a need of implementation in manufacturing lines formed by multiple machines and controlled by multiple operators (Sherali, 2008). When a changeover is being run in a manufacturing cell, the SMED methodology is not specific about how the set-up time should be measured (Ferradás, et al. 2013).

Finally, although changeover reduction literature is extensive, not adequate attention to team performance during SMED programs is being given (Ferradás, et al. 2013). SMED improvement program should involve the process identification and changeover analysis, the training of the improvement team, as well as selecting the appropriate members and their responsibilities during the project. The training they receive and their motivation can be a major driver for success (G. Culley et al., 1995).

The only way to sustain the improvements is by standardizing and controlling the new methodology, as well as continuous monitoring of all the set-up times (McIntosh, et. al, 2000)

2.2.9. Limitation of implementation

Ferradás and Salonitis (2013) affirm that SMED implementation cannot be focused only in methodology since the result can be extremely poor. In contrast, combining design modifications with methodology improvements, the outputs can be acceptable with a moderate investment. The design of a new system is out of scope when implementing SMED programs, although results can be excellent.

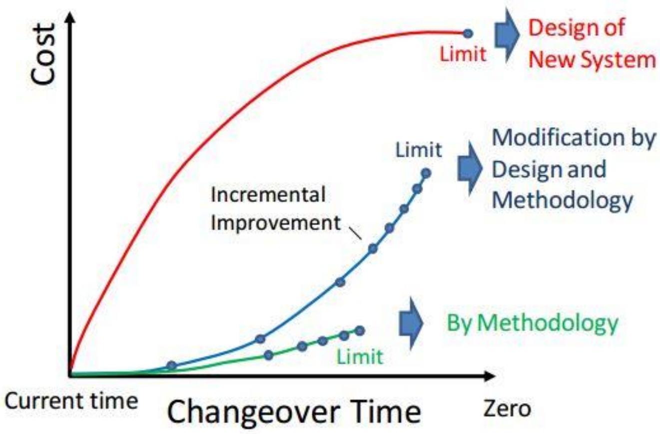


Figure 13 - Limits and costs of changeover improvement strategies (Cakmakci, 2009)

SMED methodology is mainly focused on organizational improvements and not focusing enough on equipment design improvements. Organization improvements are focusing on changing the way the people work. In contrast, design based improvements put attention on physically modifying manufacturing equipment.

Chapter 3

Description of Process and Equipment

3.1. Electron Beam Machine

An electron beam is emitted by a cathode fitted on top of an accelerator tube an example of an accelerator tube can be seen in the below figure. The electrons are produced by the overheating of a cathode filament under vacuum and they are further attracted into the accelerating section of the tube by an electrical extraction field.

Figure 14 - Accelerator Tube (Zaidah)

The electrical field is generated by an Insulated Core Transformer (ICT). This generator also powers the cathode circuit at High Voltage side for beam emission. The core of a transformer is divided into insulated segments, each having a secondary winding which drives its own rectifier. The high magnetic flux through the core induces alternating voltages up to several hundreds of kV in each individual sections. The rectifier outputs are connected in series to produce the high voltage. As in the cascade generator, the series-connected dc voltages of the individual sections yield an output voltage of the order of several hundred thousand or several million volts. These generators can accelerate high intensity beams (Cottereau, 2001).

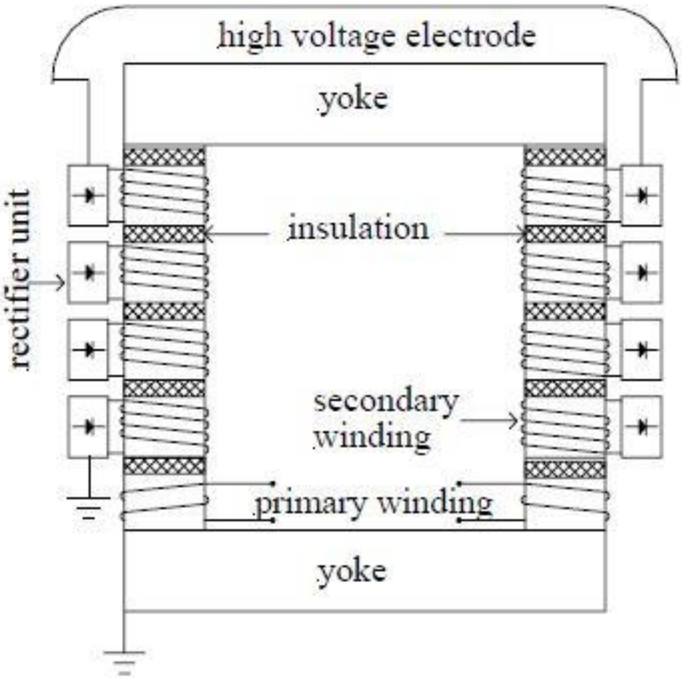


Figure 15 - ICT Schematic (Cottereau, 2001)

A constant field accelerates this beam by communicating kinetic energy to the electrons. A 1 eV (energy unit in the ISO system) is the energy acquired by one electron travelling 1 Volt potential difference.

The accelerated electrons travel under high vacuum through a scanner device that constantly sweeps the beam along two directions (X and Y) by electromagnetic fields. This high vacuum is limited by the cathode, who generate the electrons, and by a titanium sheet with a very small thickness called window.

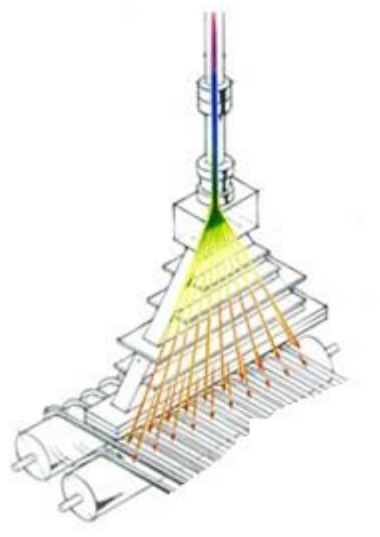


Figure 16 - High Vacuum line representation (Derywooktech)

3.1.1. Handling

Before the irradiation process the PE should be extruded, the material (in grain) is melted, color is applied and is applied in the conductor (in this specific case we will be using copper, copper alloys or aluminum). In the end of an extrusion line a spooler is installed where the wire is collocated in a reel to be crosslink.

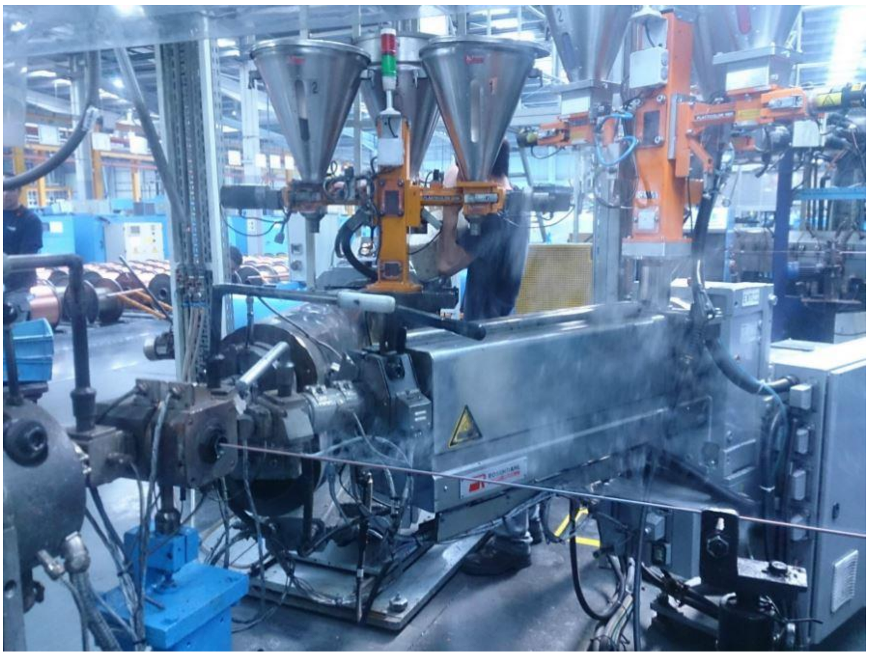


Figure 17 - Extrusion Process (Photo by the author)

Such reel have different length, due to the wire cross-section, diameter and clients requests (reduction of stocks). Such reel are denominated as D800 due to their diameter. After extrusion, the spools are driven by truck or forklift until the irradiation area.

Figure 18 - Reels (Photo by the author)

The cables who was wound in reels on extrusion are fed by a pay-off (Figure 16) into the radiation field undergoing several passes.

Figure 19 - Pay-off equipment (Photo by the author)

Then, the wire is rewound into take-up spooler (Figure 17), if the wire did not have any defect the spool is considered as finished. The length in the spool will depend on wire diameter and client request.

Figure 20 – Spooler (Finished product) – (Photo by the author)

In order to achieve the desired crosslinking degree and homogeneity, the optimum working point of an electron-beam crosslinking facility has to be defined. This is given by the appropriate selection of the suitable equipment (electron-beam accelerator and cable handling), the electron-beam acceleration voltage, the electron-beam current, and speed. These parameters influence the dose, expressed in Gray (1 Gy = 1J/kg, ISO unit) and characterize the amount of energy received by the mass of product after its travel through the scanned Electron Beam. The thickness of the insulation is critical to perform an optimal recipe to the wire, the energy must be sufficient to penetrate the total thickness of the material presented to the beam.

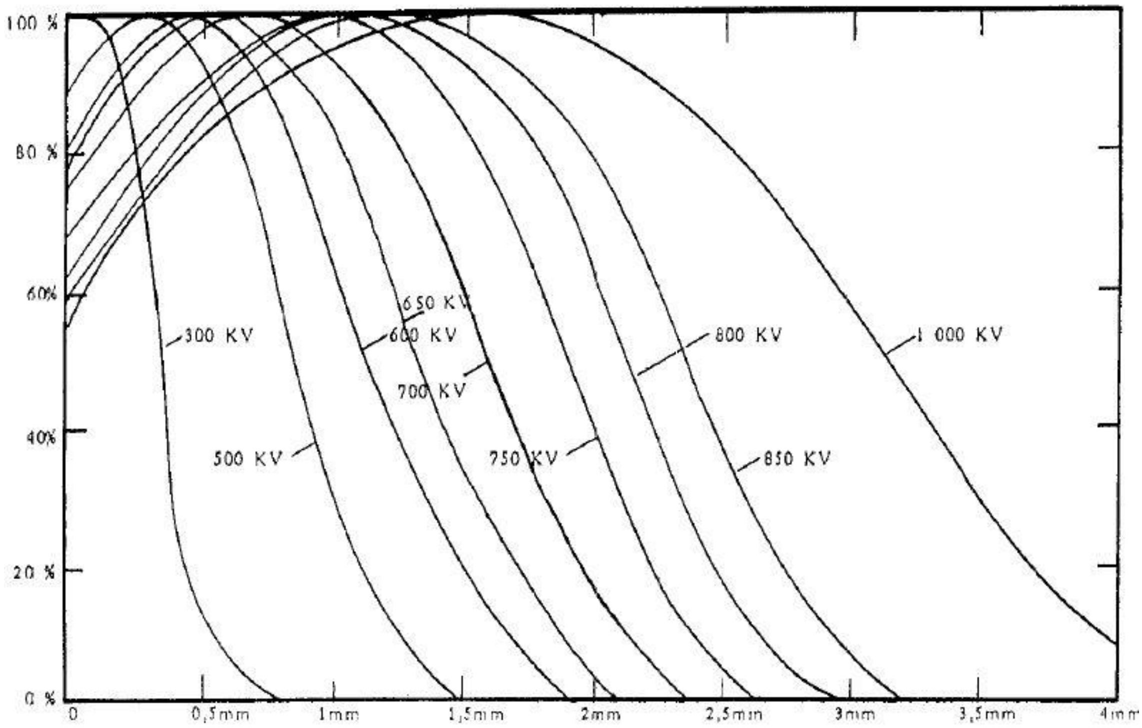


Figure 21 - Dose Distribution Curve (A. Wambersie, 1967)

This can be quantitatively predicted with the simulation, leading to a controlled and optimized process, a fine tuning of the cable properties, the reduction of scrap, and economization of raw materials.

3.1.2. Benefits for products

It is a convenient method for vulcanizing, polymerizing, curing or crosslinking that creates original molecule bonds among organic compounds. By nature, every structure can be crosslinked with little energy requirement using accelerated electrons, as long as the geometric characteristics and the compound peculiar conditions are satisfied.

The electron beam machine where the methodology presented here was applied are used to crosslink poly-ethylene (PE). Crosslinking PE modify drastically their characteristics and provide particularities that are unreachable without this process.

- Thermic: Thermoplastics are made up of long chain molecules. As the plastic is heated up these can slide past each other causing the material to soften and finally melt. PE is quite resistant to heat and melt. It will not melt but will carbonize at temperature above 300ºC. PE retain his flexibility and other characteristics at lower temperatures, until -40ºC approximately. The minimum and maximum permissible temperature are standardized by international norms and in, such cases, by internal norms provided per clients.

- Electrical: Electrical properties, who are extremely important since the electron beam machine are used in automotive wires, don't suffer any modification. But, PE have a high factor temperature loss and a dielectric constant insignificant. In term of comparison, dielectric wire loss of a PVC wire is five time superior of a PE wire.
- Mechanical: PE have an excellent behavior against stress such as abrasion, bend, stretch, etc.
- Chemical: Due to the crosslink process, PE is very resistant against acid, oils or solution with a high pH value.

3.1.3. Other applications

Electron-beams are used for many other applications besides crosslinking of wire and cable products.

Polymer modification	Production of heat shrink tube Floor heating pipes Production of shrink-wrap foils for foodstuffs and general packaging Partial curing of tyres components Curing of surface coatings and printing
Sterilization	Medical products Food Sewage treatment
Metal working	Electron beam welding Surface treatment
Health care	Cancer Therapy

Table 3 - Other application for electron beam machine

The energy that is used to modify the polymer is delivered directly by the electrons. This allows the process to be precisely regulated and controlled. In the same way as in a television tube the electrons are accelerated in a vacuum by a high voltage but instead of striking the screen they strike the product to be crosslinked.

Chapter 4

Framework

4.1. Company description

Coficab Portugal is composed by three Manufacturing Units, one Warehouse and a Technical Center where R&D department is developing all new wires and products.

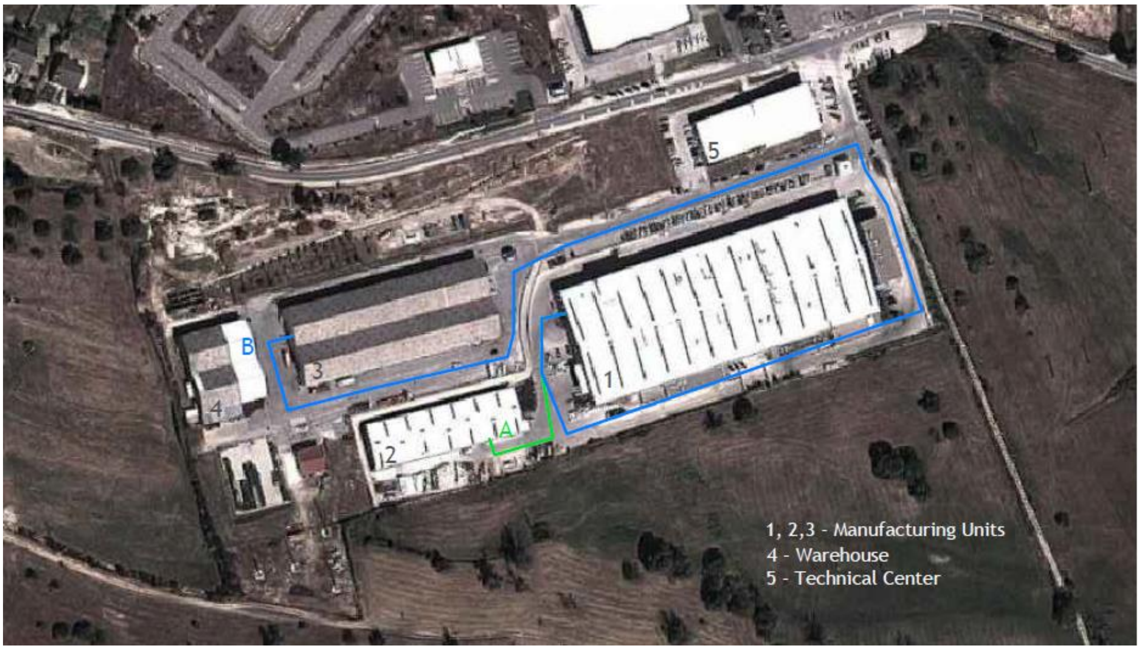


Figure 22 - Coficab Portugal – Google Maps View

Since each machine have their own specificities, the electron beam machine supplier, Vivirad, gave for each machine different names. To ease up what machine are we talking about those nomenclatures will be used in this project since also, each manufacturing unit have his own irradiation area. Tuna is in Manufacturing unit 1, Farrusco in Manufacturing 2 and, finally, Cora in Manufacturing Unit 3.

Figure 23 - Inline electron beam machine (Tuna) - (Photo by the author)

Tuna is considered an inline electron beam machine since the extrusion and irradiation are done in one production line only in contrast with Farrusco and Cora where the irradiation is considered as offline. The extrusion is done before in other production lines. SMED methodology will not be used in Tuna, for now.

Figure 24 – Offline Electron beam machine (Cora) – (Photos done by the author)

4.2. SMED implementation program

A group was formed inside Coficab Company to implement the SMED methodology. This multi-functional group is formed by Production, Maintenance, Industrial performance, EHS (Environment, Health and Safety), Corporate Process Engineer departments and finally by the Plant Manager of Coficab Portugal. In total, six persons are involved in this workshop. The supplier of the electron beam machine will give support if necessary.

According with Kusar model presented in chapter two and after the first meeting of the team a schedule and schema was approved. This schema is represented in the figure below.

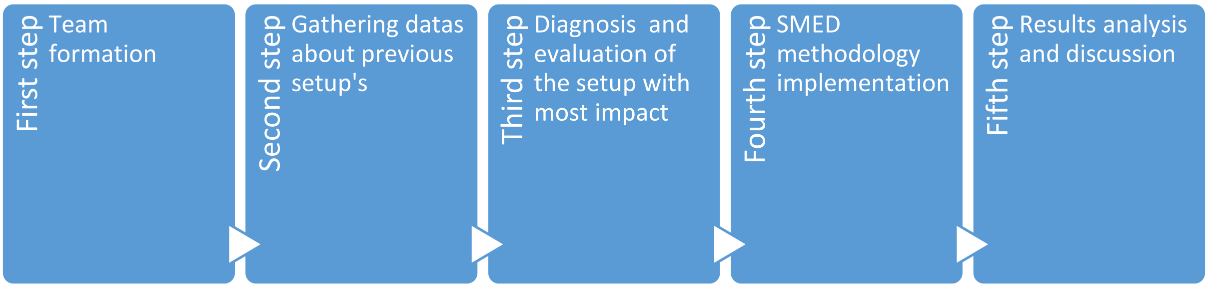


Figure 25 - Different steps applied in this project (Graph done by the project)

4.3. Setup analysis

During irradiation process, they exist two main setup's types who can be divided in different types also.

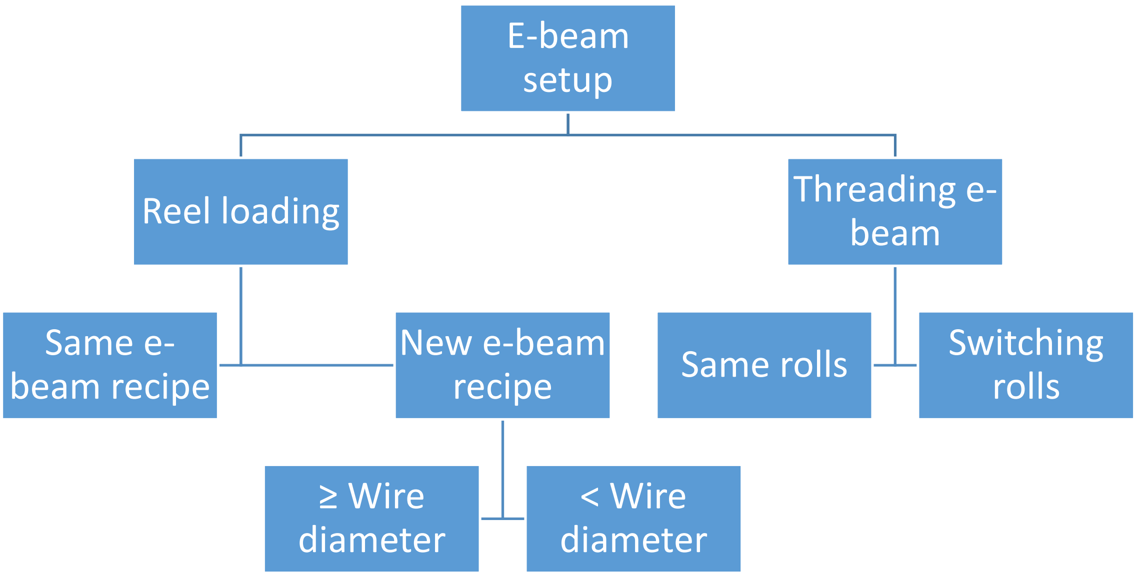


Figure 26 - Type of setup in e-beam (Graph done by the author)

Reel loading with the same recipe means that the operator will load a new reel with the same reference that it was doing previously. In contrast, the operator can have to load a new recipe to crosslink a new reference and this reference can have, or not, a different diameter. The diameter difference have a massive impact in set up as we will see further.

Threading e-beam is normally done when the wire break in the production line. In this particular case there is no need to switch the rolls inside the conveyer. They exist different rolls regarding the wire diameter to crosslink if the difference of the two reference is too high the operators can be obliged to load new rolls in the e-beam. A production instruction was created for the different rolls and when they need to change them. Only Farrusco uses different type of rolls.

A data collection of different type of setups in April 2016 was done to get historical data and comparison between before and after SMED implementation.

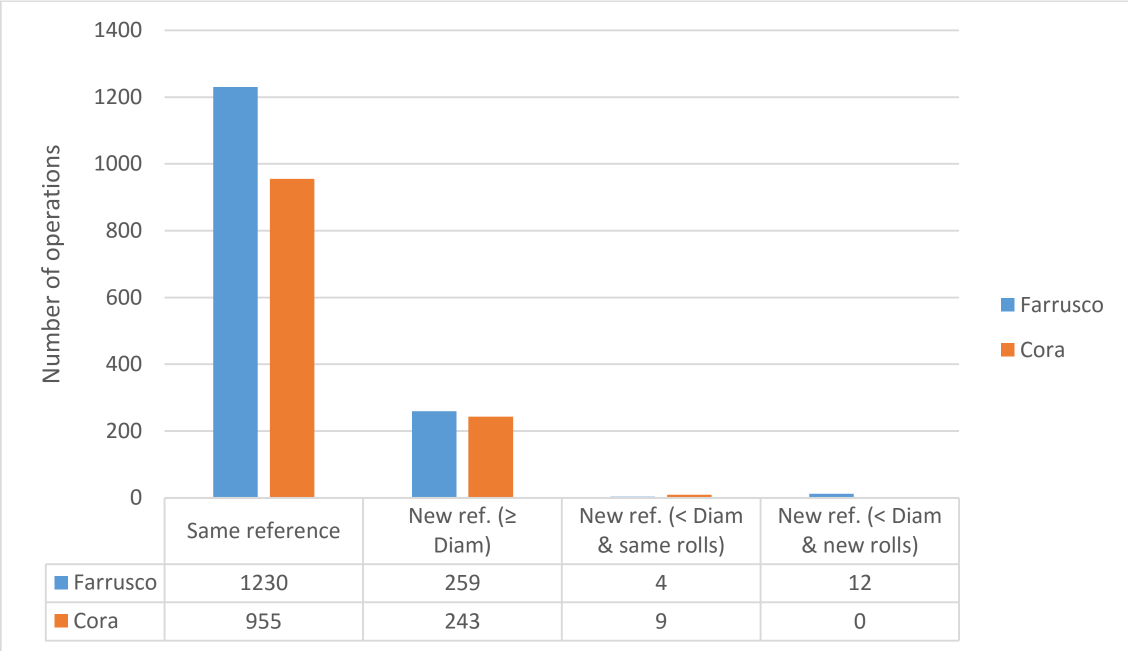


Figure 27 - Number of operations during April 2016 (Graph done by the author)

It is clear that during production *reel loading* operation is the most common of all activities and it is done more often in Farrusco than in Cora. This difference between Cora and Farrusco is due to the larger variety of wires and cables that Farrusco can handle. Due to his ICT capacity, higher than Cora, the machine can handle battery cable, since the diameter of the battery cable is higher than standard wire the length in the D800 spool is lower so the operators needs to load more spools per shift.

Loading reels (independently of the wire diameter) represent % of the setup time in irradiation process. Due to this massive impact, this SMED workshop we will be dedicated to reduce the time of loading reels. In parallel, some improvements will be suggested for further workshops.

Chapter 5

SMED Implementation

5.1. Stage 0 (Preliminary stage)

During April 2016, a diagnosis of the actual setups time was done by Corporate Process Engineer member with the support of Industrial Performance Department. The analysis can be seen in Figure 22 and 23. The average time presented in this analysis englobe the last spool produced at production speed (Ramp down) until production speed is achieved again are included (Ramp up).

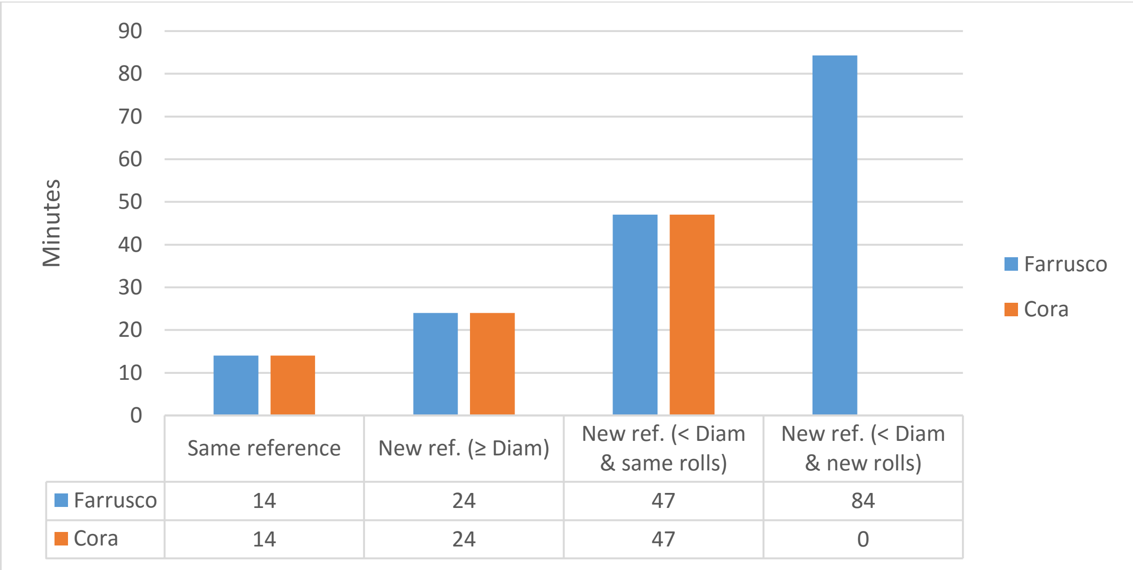


Figure 28 - Setup before SMED Workshop (Graph done by the author)

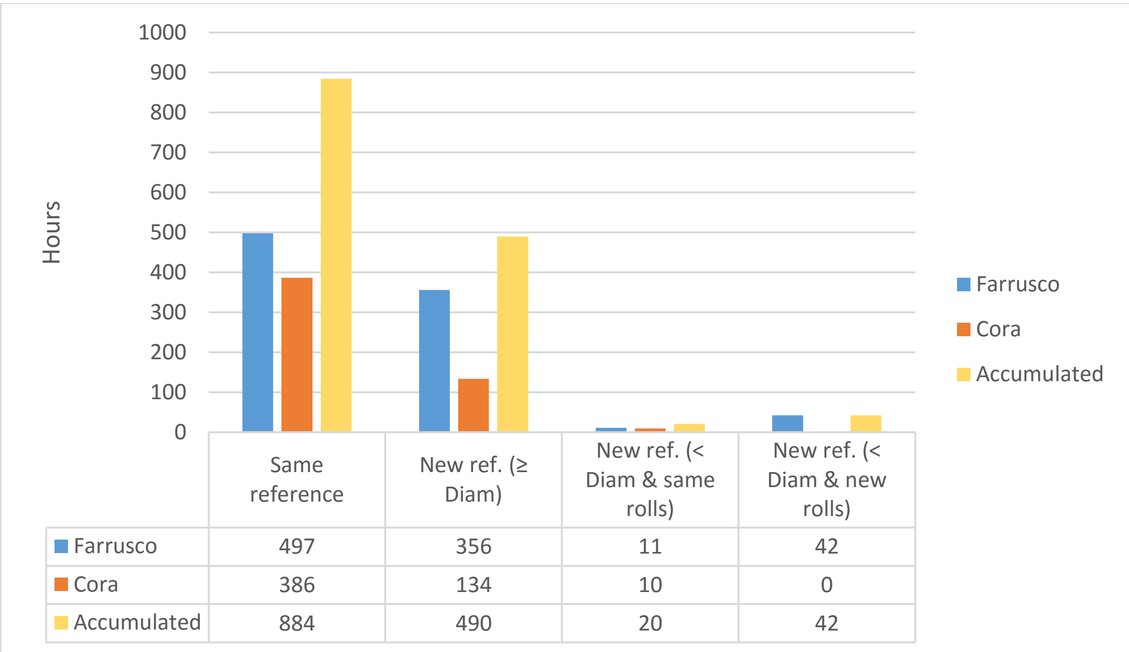


Figure 29 - Setup time analysis during April 2016 (Graph done by the author)

We can verify that loading reels on Farrusco (independently of the diameter of the wire) took 451 hours, this is equivalent of more than 18 days.

In table 4 all tasks regarding the different setups can be applied. According Kusar model, internal and external activities are not separated yet. A differentiation between each setup was also provided.

Actions	Time of the operation (s)	Setup			
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)
Preparing new spool					
Taking out the reel of the pallet	10	X	X	X	X
Rolling reel until pay-off area	5	X	X	X	X
Striping both ends	10	X	X	X	X
Putting duct-tape in the end of the spool	5	X	X	X	X
Stopping machine					
Reducing speed in the last spool	300	X	X	X	X
Stopping e-beam	50	X	X	X	X
Threading					
Drain out all wire inside e-beam	300				X
Deconditioning e-beam	60		X	X	X
Open e-beam door	180			X	X
Switching rolls	1200				X
Threading e-beam	500			X	X
Threading rest of production line	300			X	X
Close e-beam door	60			X	X
Choosing recipe	10		X	X	X
Conditioning e-beam	310		X	X	X
Taking out empty spool					
Open pay-off door	5	X	X	X	X
Unbrake spool	5	X	X	X	X
Take out wire tension	2	X	X	X	X
Put some wire on the door lock to avoid unstringing of the pay-off	3	X	X	X	X
Cutting wire	1	X	X	X	X
Close door	2	X	X	X	X
Platform up	5	X	X	X	X
Unlock spool	3	X	X	X	X
Platform down	5	X	X	X	X
Spool take out	2	X	X	X	X
Loading new spool					
Putting spool in pay-off	5	X	X	X	X
Platform goes up	5	X	X	X	X
Lock spool	3	X	X	X	X
Platform go down	5	X	X	X	X
Node between spool	60	X	X	X	X
Lock spool	1	X	X	X	X
Taking out the wire put in task 3	5	X	X	X	X
Put connection to ground	30	X	X	X	X
Put duct tape in spool	10	X	X	X	X
Put duct tape in node	2	X	X	X	X
Put tension in the wire	3	X	X	X	X
Close door	2	X	X	X	X
Connect pay-off	1	X	X	X	X
Starting machine					

Start e-beam (Ramp up)	300	X	X	X	X

Table 4 - Tasks in Stage 0 (Graph done by the author)

5.2. Equipment's and operator impact on setup

Based on the data collected, a separation between the impact of the tasks done by the operators and by the different equipment's (pay-off and e-beam) was done. We can clearly see that the equipment's have an important impact in setup tasks.

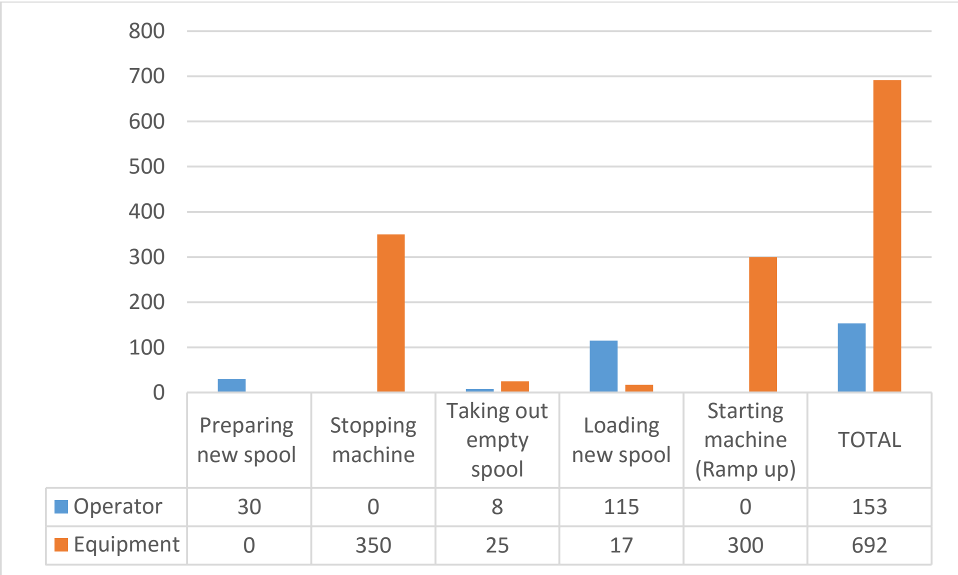
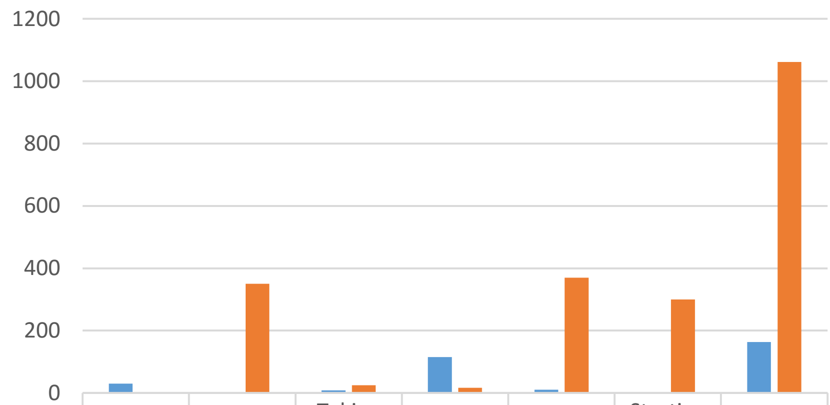


Figure 30 - Analysis of a setup with reels with the same reference - (Graph done by the author)

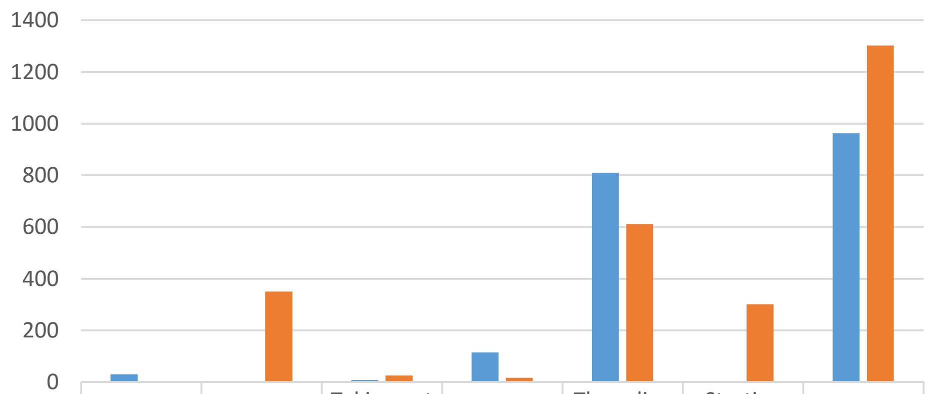
The equipment's have an important impact in this setup. As a note, we consider in this analysis (and in the further ones) "*Stopping machine*" as the moment when the last spool at normal speed is produced until a complete stop of the e-beam.



	Preparing new spool	Stopping machine	Taking out empty spool	Loading new spool	Loading new recipe	Starting machine (Ramp up)	TOTAL
Operator	30	0	8	115	10	0	163
Equipment	0	350	25	17	370	300	1062

Figure 31 - Analysis of a setup with reels with different diameters (equal or higher) - (Graph done by the author)

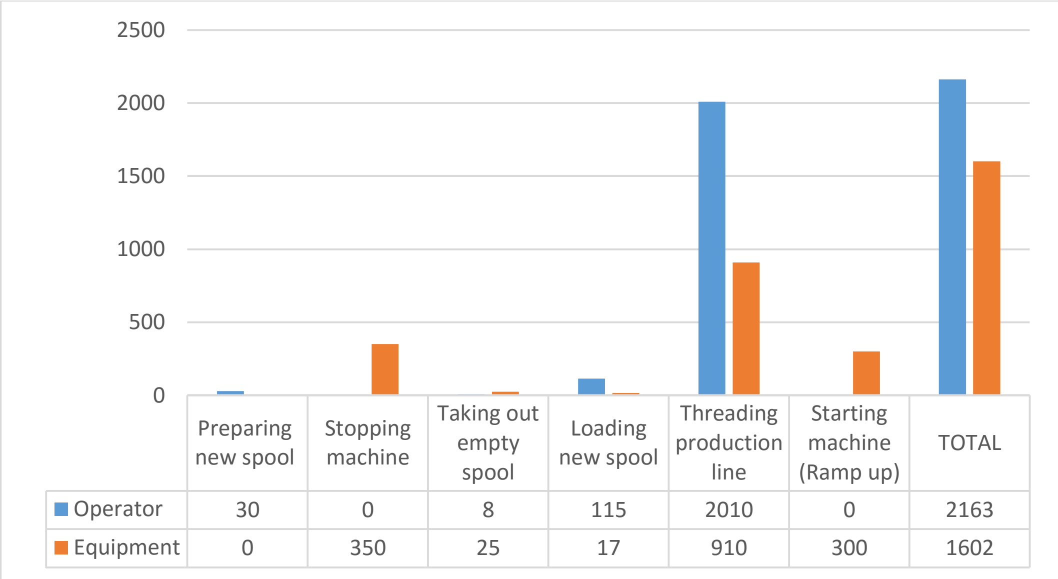
As seen before the equipment's have also an important impact in this type of setup. The difference between the previous one is that the operator need to load a new recipe in the e-beam. This loading take six minutes (± 10 seconds, depending on ICT Tension).



	Preparing new spool	Stopping machine	Taking out empty spool	Loading new spool	Threading production line	Starting machine (Ramp up)	TOTAL
Operator	30	0	8	115	810	0	963
Equipment	0	350	25	17	610	300	1302

Figure 32 - Analysis of a setup between reels with different diameters (lower but with same rolls) - (Graph done by the author)

As explain before, the wire diameter has an important impact in reels setups. Inside the e-beam the wire is exposed to the different kind of stresses, one of them is the stretch caused by the several passes in the rolls. Each time that the wire is passing by a roll it should stretch few millimeters (depending on the cross-sections), but after several passages the wire cannot stretch more and will break. When a wire break occur the e-beam need to be thread again.



	Preparing new spool	Stopping machine	Taking out empty spool	Loading new spool	Threading production line	Starting machine (Ramp up)	TOTAL
Operator	30	0	8	115	2010	0	2163
Equipment	0	350	25	17	910	300	1602

Figure 33 - Analysis of a setup between reels with different diameters (lower but with new rolls) - (Graph done by the author)

Depending on the new wire diameter in production it can be necessary to switch a set of rolls inside Farrusco (due to limitations presented earlier in this project Cora is producing always with the same rolls). The difference between figure 26 and 27 is due to the time that the operators need to change them. As a note, a SMED workshop will be done further to improve this operation.

5.3. Stage 1 (Separate internal and external setups)

According Stage 0 it is clear that the equipment's have an important impact independently of the type of the setup. However, as a first step the setup tasks realized by the operators was separated as intern/extern setup and a deeply evaluation was done to verify the possibility of converting internal into external setup.

To complete and also to increase the probability of a correct setup the operators need to use different tools such as scissors to cut wire and duct tape. Those complements are always available and with the operators in their uniforms.

Actions	Time of the operation (s)	Setup				Internal/External	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Preparing new spool							
Taking out the reel of the pallet	10	X	X	X	X		X
Rolling reel until pay-off area	5	X	X	X	X		X
Striping both ends	10	X	X	X	X	X	
Putting duct-tape in the end of the spool	5	X	X	X	X	X	
Stopping machine							
Reducing speed in the last spool	300	X	X	X	X	X	
Stopping e-beam	50	X	X	X	X	X	
Threading							
Drain out all wire inside e-beam	300				X	X	
Deconditioning e-beam	60		X	X	X	X	
Open e-beam door	180			X	X	X	
Taking out rolls in production	200				X	X	
Transport of the new rolls until e-beam area	120				X	X	
Switching supports from old rolls to new ones	120				X	X	
Putting new rolls	760				X	X	
Preparing rope to thread e-beam	60			X	X	X	
Threading e-beam	440			X	X	X	
Threading rest of production line	300			X	X	X	
Close e-beam door	60			X	X	X	
Choosing recipe	10		X	X	X	X	
Conditioning e-beam	310		X	X	X	X	
Taking out empty spool							
Open pay-off door	5	X	X	X	X	X	
Unbrake spool	5	X	X	X	X	X	
Take out wire tension	2	X	X	X	X	X	
Put some wire on the door lock to avoid unstringing of the pay-off	3	X	X	X	X	X	
Cutting wire	1	X	X	X	X	X	
Close door	2	X	X	X	X	X	
Platform up	5	X	X	X	X	X	
Unlock spool	3	X	X	X	X	X	
Platform down	5	X	X	X	X	X	
Spool take out	2	X	X	X	X	X	
Loading new spool							
Putting spool in pay-off	5	X	X	X	X	X	
Platform goes up	5	X	X	X	X	X	
Lock spool	3	X	X	X	X	X	
Platform go down	5	X	X	X	X	X	
Node between spool	60	X	X	X	X	X	
Lock spool	1	X	X	X	X	X	
Taking out the wire put on door lock	5	X	X	X	X	X	
Put connection to ground	30	X	X	X	X	X	
Put duct tape in spool	10	X	X	X	X	X	
Put duct tape in node	2	X	X	X	X	X	
Put tension in the wire	3	X	X	X	X	X	
Close door	2	X	X	X	X	X	
Connect pay-off	1	X	X	X	X	X	
Starting machine							
Start e-beam (Ramp up)	300	X	X	X	X	X	

Table 5 - Tasks and sequence in Stage 1 - (Table done by the author)

Figure 34 shown the production losses during the setup period.

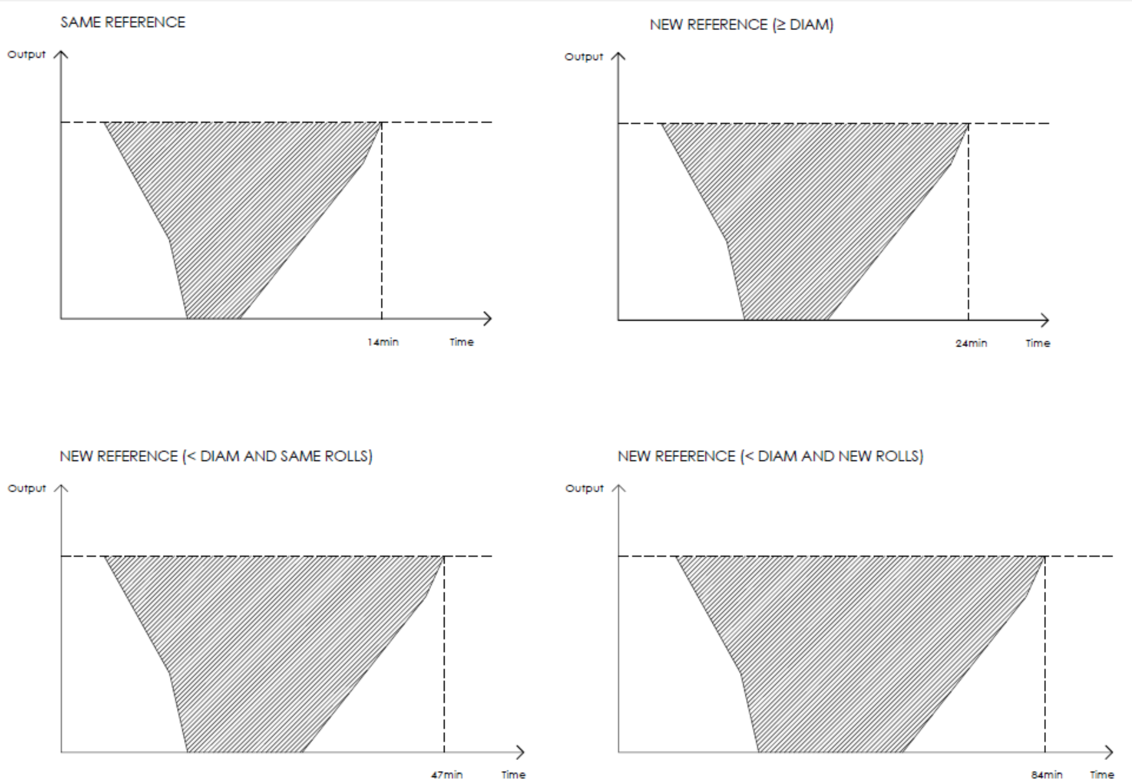


Figure 34 - Production losses during setups (Stage 1) - (Graph done by the author)

5.4. Stage 2 (Convert internal setup into external setup)

This stage can be considered as a complement of the collaborators work, since by their own initiative they develop methods and best practices to reach productivity requests and facilitate their own job. We complete their work.

In that point, only the actions/tasks considering actually the reel changes and/or recipe are considered so *switching of the rolls* will be considered no more.

Preparing new spool

Tasks	Time of the operation (s)	Setup				Internal/External	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Taking out the reel of the pallet	10	X	X	X	X		X
Rolling reel until pay-off area	5	X	X	X	X		X
Striping both ends	10	X	X	X	X		X
Putting duct-tape in the end of the spool	5	X	X	X	X		X

Stopping machine

Tasks	Time of the operation (s)	Setup				Internal/External	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Reducing speed in the last spool	300	X	X	X	X	X	
Stopping e-beam	50	X	X	X	X	X	

Threading

Tasks	Time of the operation (s)	Setup				Internal/External	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Drain out all wire inside e-beam	300				X	X	
Deconditioning e-beam	60		X	X	X	X	
Open e-beam door	180			X	X	X	
Preparing rope to thread e-beam	60				X		X
Threading e-beam	440			X	X	X	
Threading rest of production line	300			X	X	X	
Close e-beam door	60			X	X	X	
Choosing recipe	10		X	X	X		X
Conditioning e-beam	310		X	X	X	X	

Taking out empty spool

Tasks	**Duration (s)**	**Setup**				**Internal/External**	
		Same ref.	**New ref. (≥ Diam)**	**New ref. (< Diam & same rolls)**	**New ref. (< Diam & new rolls)**	**Int.**	**Ext.**
Open pay-off door	5	X	X	X	X	X	
Unbrake spool	5	X	X	X	X	X	
Take out wire tension	2	X	X	X	X	X	
Put some wire on the door lock to avoid unstringing of the pay-off	3	X	X	X	X	X	
Cutting wire	1	X	X	X	X	X	
Close door	2	X	X	X	X	X	
Platform up	5	X	X	X	X	X	
Unlock spool	3	X	X	X	X	X	
Platform down	5	X	X	X	X	X	
Spool take out	2	X	X	X	X	X	

Loading new spool							
Tasks	**Duration (s)**	**Setup**				**Internal/External**	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Putting spool in pay-off	5	X	X	X	X	X	
Platform goes up	5	X	X	X	X	X	
Lock spool	3	X	X	X	X	X	
Platform go down	5	X	X	X	X	X	
Node between spool	60	X	X	X	X	X	
Lock spool	1	X	X	X	X	X	
Taking out the wire put in task 3	5	X	X	X	X	X	
Put connection to ground	30	X	X	X	X	X	
Put duct tape in spool	10	X	X	X	X		X
Put duct tape in node	2	X	X	X	X	X	
Put tension in the wire	3	X	X	X	X	X	
Close door	2	X	X	X	X	X	
Connect pay-off	1	X	X	X	X	X	
Starting machine							
Tasks	**Duration (s)**	**Setup**				**Internal/External**	
		Same ref.	New ref. (≥ Diam)	New ref. (< Diam & same rolls)	New ref. (< Diam & new rolls)	Int.	Ext.
Start e-beam (Ramp up)	300	X	X	X	X	X	

Table 6 - Tasks and sequence in Stage 2 - (Table done by the author)

Converting internal setup into external does not have an important impact in setup, since the setup was reduced only by 35 seconds, as we can see in table 6.

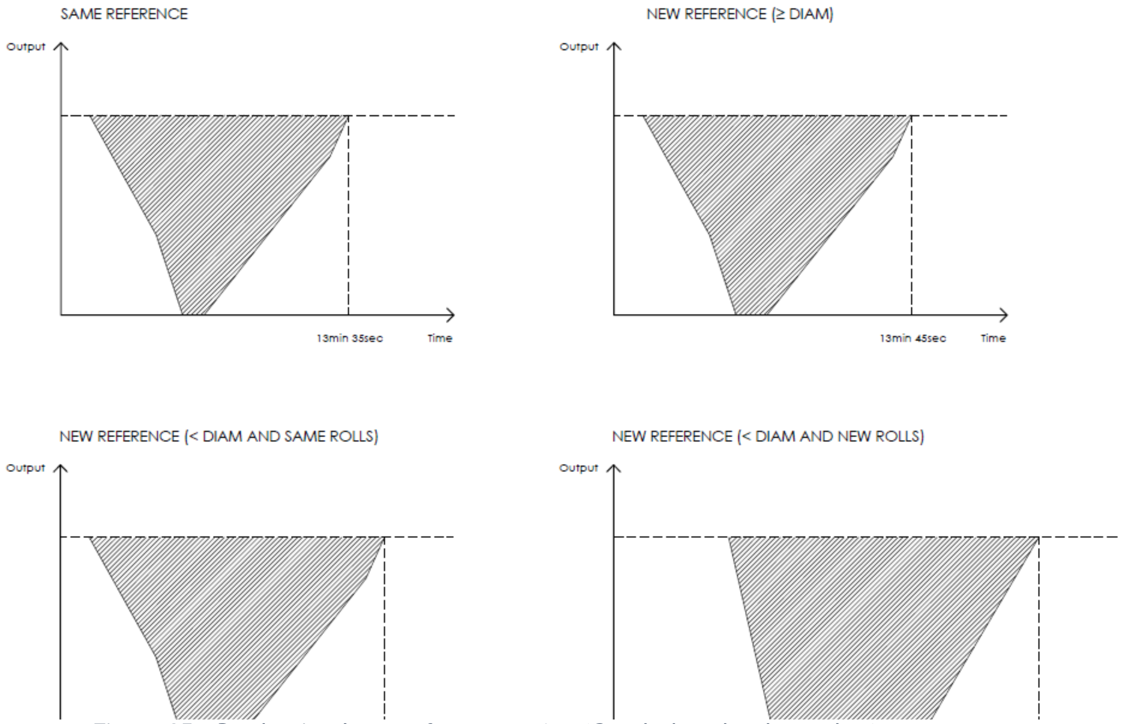


Figure 35 - Production losses after stage 1 - (Graph done by the author)

The number of tasks done internally decrease and this modification did not have also a harmful impact in the other activities.

In the operator perspective it is also clear that those modifications are also beneficial to them and do not increase or add more works or tasks to them, it was only a way to use more widely and efficiently their own time.

5.5. Stage 3 (Streamline operations)

In this stage, the workshop was reengineering the setup, focusing in two main questions:

- Are the tasks done until now really needed?
- Since the role of the equipment have such a big impact can they be modified to reduce setup time?

Every actions and tasks was analyzed to verify their obligation. Per each of them two questions was asked “Do I have actually to do this?” and “Is it possible to do it quicker?” Several trials was done by Industrial Performance, Corporate Process Engineer with supervision of Production and HSE Department.

In table 7, the activities done in the e-beam and in the pay-off was separated and analyzed from their obligation perspective. This perspective include the security for operators, equipment and if any detrimental impact is provoked to the product.

		Pay-off	E-beam	Obligation
Stopping machine				
Reducing speed in the last spool	300		X	
Stopping e-beam	50		X	X
Threading				
Deconditioning e-beam	60		X	
Open e-beam door	180		X	
Preparing rope to thread e-beam	60		X	
Threading e-beam	440		X	
Threading rest of production line	300		X	
Close e-beam door	60		X	
Choosing recipe	10		X	X
Conditioning e-beam	310		X	
Taking out empty spool				
Open pay-off door	5	X		X
Unbrake spool	5	X		X
Take out wire tension	2	X		X
Put some wire on the door lock to avoid unstringing of the pay-off	3	X		X
Cutting wire	1	X		X
Close door	2	X		
Platform up	5	X		
Unlock spool	3	X		X
Platform down	5	X		
Open pay-off door	5	X		
Spool take out	2	X		X
Loading new spool				
Putting spool in pay-off	5	X		X
Close door	2	X		
Platform goes up	5	X		X
Lock spool	3	X		X
Platform go down	5	X		X
Open pay-off door	5	X		
Node between spool	60	X		X
Lock spool	1	X		X
Taking out the wire put in task 3	5	X		X
Put connection to ground	30	X		X
Put duct tape in node	2	X		X
Put tension in the wire	3	X		X
Close door	2	X		X
Connect pay-off	1	X		X
Starting machine				
Start e-beam (Ramp up)	300		X	X

Table 7 - Mandatory analysis per equipment - (Table done by the author)

Regarding the pay-off, almost 40% of the time can be considered as not mandatory and can be avoided if the equipment will be upgraded.

Until now, the reel can only be load or unload when the pay-off door is closed, if the door remains open the reel cannot be unlock or any movement from the platform is allowed. A software upgrade will correct this situation, it will spare twenty-four seconds per setup independently of setup type.

Grounding the reel (Put connection to ground) is mandatory for the process, since the beam generated in the e-beam is reaching the conductor of the wire. Due to the electricity generated the reel became a massive capacitor, the electricity in it should be discharged to avoid Quality problems. A special tool was created to that. Grounding the reel tarry forty seconds, all this time was converted into extern setup.

In brief, the upgrades and new tools applied in pay-off spares sixty-four seconds in setup, more than 40% of total time setup related with pay-off.

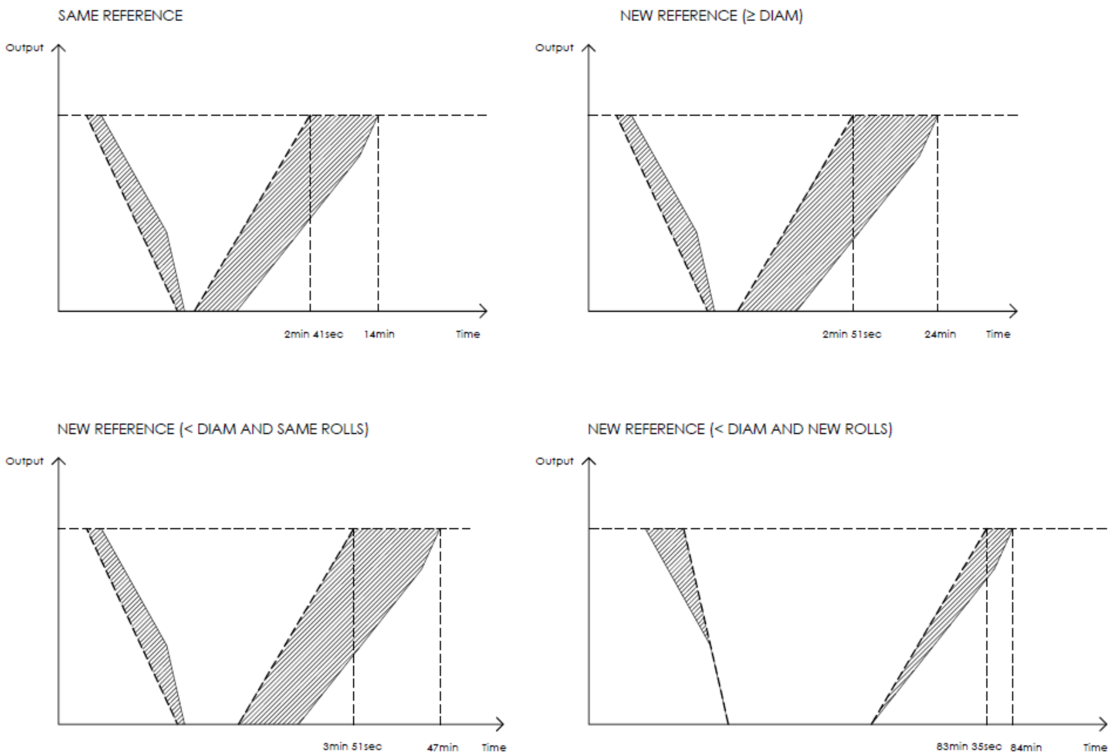


Figure 36 - Matching between stage 1 and 3 production losses - (Graph done by the author)

Regarding the e-beam itself, the operators was reducing the speed production in the last spool to avoid, supposedly, breaks in the wire. Several trials was performed in Cora and Farrusco with different diameters, cross-sections and at production speed different and in any case a break was verified. This reduce the setup in five minutes (± 1 minute depending on the wire diameter). Also, ramping up the e-beam was done in two steps, as we can see in figure 23 when the speed change. The operators are running in a lower speed the machine due to the node between the two spools (the finished and new one), the operators had as assumption that the node can break, and we prove also that, if done correctly, the node cannot break so they can ramp up the machine from 0 m/min to full speed.

Due to the large amount of references that Coficab is producing and since that the operator has to deconditioning and conditioning the e-beam each time that a new reference will be produced, *unloading* and *loading* a new recipe have a big impact in production, as proven in Figure 24. Those actions was avoided upgrading the e-beam's software. This upgrade allow to approximate *loading a reel with the same reference* and *loading a reel with a higher diameter* setups in duration. This second type of setup decrease now more than 55%.

Also, as explain before, the wire diameter have an important when the operators are loading new references. If the diameter of the wire is lower than the wire in production before the wire will break inside the e-beam due to the stretch applied in the several passages in the rolls. This stretch cannot be eliminated but can be absorb by a more elastic material. A standard elastic rope was added between the spools with excellent results since no more breaks was verified. The action *Node between spool* who his shown in table 7 increase into 120 seconds (± 10 seconds) but since this added tool avoid that the wire breaks inside the e-beam threading e-beam and all complementary activities (Deconditioning e-beam, preparing rope to thread it, open and threading, closing and conditioning e-beam) are not executed, sparing at all more than 23 minutes. Loading a reel with a lower diameter was taking forty-seven minutes before the workshop, now it take less 75%.

Chapter 6

Final considerations

This workshop permit to entrench Lean Manufacturing and their inherent tools. Coficab is a company where such philosophy is clearly applied, anyway, in this workshop a different perspective and approach was applied regarding SMED.

This workshop was done in COFICAB Portugal but COFICAB had more electron beam machine in plants around the world. The modifications will be also applied in those equipment's.

6.1. Results critics

The translation of internal setup into external setup did not have such important impact in this workshop. However, the modifications of the equipment have a strong impact as said by Ferradás and Salonitis in 2013.

This SMED workshop was focused in five main questions regarding Security (for equipment and operators), Process, Investment, Communication and Teamwork:

1. In any case that a step fail, the associated risks are known and controlled?
    - Many other upgrades can be done and considered to have better results in this SMED workshop but they could results in, for example, wire breaks. Who will affect severely the production since, as explain before, threading the e-beam or even all the production line last for more than thirty minutes.
    - All modifications applied have not associated new risks for operators, product and/or equipment. For example, grounding the wire had risk associated since if the grounding was not done properly it could damage the wire. With the new tool this risk is now almost null.

2. With today's technology the modification proposed can be implemented?
    - Several upgrades was done in the pay-off and e-beam. Regarding software upgrades all of them was done in PLC (Programmable Logic Controller). Those upgrades are not related actually with advances or new technology, they can be considered as improvements due to production and process requests. All of them, without exception, was discussed by all members of this SMED workshop. A strong commitment and knowledge about the systems, equipment and processes are very important for such modifications.
    - The cooperation between the company and his suppliers to develop software and/or hardware is very important to the success and continuous improvement of the process. Both suppliers was involved in this workshop.

3. In case of software and/or hardware modification, the payback period is calculated?

- During the meetings between all members of the team the payback was calculated taking into account labor, equipment and period when the machine should be stopped.
- The software modifications was done internally by one technician from Maintenance Department, the payback was quickly achieved.
- Hardware modifications was supported by the supplier of the pay-off. Payback period, where is included the development, prototypes and trials, was described and agreed by Management.

4. The security for operator and machine remain the same as before?
    - Due to the specificity and complexity of the equipment, any modification in the process should be done with the supervision of collaborators that have a strong knowledge about it. Corporate Process Engineer also as Maintenance Manager aware of any modifications.
    - The security of the operators was always the biggest concern during all the workshop. Any modification was done if the probability of any injury increase. For controlling and adverting us in the security perspective, HSE was involved since the first step of the implementation of this project.

5. All the persons (operators, different departments, plant manager) are involved in the process?
    - As demonstrated in this project a multidisciplinary team was created involving different collaborators and different Department from Coficab. Thus then this structural and hierarchically group, the operators of both equipment had an important role in the success of the workshop. As a critique, an operator should be involved in the team also, a selection should had be done.

Thus all this the workshop had a strong impact in the production. The multidisciplinary team created had a strong role in this success since the problems was seen from different perspective by members with their own skills and experience too, allowing that, in a first step, an idea can be considered as correct but was developed and evolved into nearly perfection. Also, motivation, communication, the dynamism as a team and also by the persons itself was the key to success.

The results had also impact in the scrap related with the process. Avoiding that the wire break inside the e-beam, and consequently scrapping the wire, spare between 2 kg's and 130 Kg's depending on the cross-section and wire diameter. If the modifications was already implemented in April (Period in analysis), the saving will be of more than XXXXXXX EUR

$$Saving = Nbr\ of\ setup\ \times Time\ saved\ per\ setup\ \times Labour\ cost\ \times nbr\ of\ operators$$

The flexibility of SMED methodology was also proven in this workshop. In matter of facts, reels are not considered as a tool but as a product. This implementation legitimize the already demonstrated flexibility of the SMED methodology.

6.2. Furthers steps

This project open new ways for further papers and researches in this area. During the literature review research, any SMED application in electron beam machine was found. Taking into account the high range where an electron beam machine can be used, we hope that the presented thesis can guide new studies.

It is also clear that new SMED workshops can be realized in Coficab regarding the setups and other modifications not so in electron beam machine but also in other processes. For example, switching the rolls was not considered but during stage 0 the members realized that the duplication of tools can decrease the time of such operations. We hope that this thesis work as a guide to that.

Bibliographic References

Arbós, L.C. - **International Journal Production Economics**, *Design of a rapid response and high efficiency service by Lean production principles: Methodology and evaluation of variability of performance*, v.80 (2002), p. 169-183. DOI: 10.1016/S0925-5273(02)00316-X

Augusto Cauchick Miguel, P. – **Produção**, *Estudo de caso na engenharia de produção: estruturação e recomendações para a sua condução*, v. 17, n. 1 (2007), p. 216-229. DOI S0103-65132007000100015

Belekoukias, I. et al. - **International Journal of Production Research,** *The impact of Lean methods and tools on the operational performance of manufacturing organizations*, vol.52, nº18, (2014). DOI:10.1080/00207543.2014.903348

Bertholey F. *et al.* – **Transfusion Clinique Biologique: Journal de la société française de transfusion sanguine,** *Work organization improvement methods applied to activities of Blood Transfusion Establishments (BTE): Lean Manufacturing, VSM, 5S*, vol. 16, nº2, (2009), p. 93-100. DOI: 10.1016/j.tracli.2009.04.007

Bown, D. – **International Journal of Service Industry Management**, *"Lean" service: in defense of a production-line approach*, vol. 9, nº3, (1990), pp. 207-225. ISSN: 0956-4233

Braglia M., Carmignani G., Zamorri F. – **International Journal of Production Research -** *A new value stream mapping approach for complex production systems*, vol. 44, issue 18-19, (2006), pp. 3929-3952. DOI: 10.1080/00207540600690545

Chan, F.T.S., **Journal of Material Processing Technology**, *Effect of Kanban size on just-in-time manufacturing systems*, vol.116, (2001), p. 146-160. DOI: 10.1016/S0924-0136(01)01022-6

Chiarini, A.; Springer, **Lean Organization: from the tools of the Toyota Production System to Lean Office**, (2013). ISBN 978-88-470-2510-3.

Coleman, B Jay, et al., **Production and Inventory Management Journal** , *Heijunka (?): A key to the Toyota production system*, vol. 35, nº4, (1994), p. 31-35. ISSN 0897-8336

Cottereau, E., *DC accelerators*, (2001).

Dennis P., Bookman, **Produção Lean Simplificada**, Second edition, 2009. ISBN: 9788577801091

Fabbri, Bruno Pinto Ferraz, *Lean Healthcare: Um levantamento de oportunidades de ganho em um hospital brasileiro*, Escola de Engenharia de São Carlos, 2001.

Ferradás Guzmán P., Salonitis K., **Procedia CIRP,** *Improving changeover time: a tailored SMED approach for welding cells*. vol. 7, (2013). DOI: 10.1016/j.procir.2013.06.039.

G.S. Dangayach, S.G. Deshmukh, **International Journal of Operations & Production Management,** *Manufacturing strategy: Literature review and some issues*, vol. 34, nº 3, (2006). ISSN: 0144-3577

Gest G., Culley, et al., **Computer Integrated Manufacturing Systems**, *Review of fast tool change systems*, vol. 8, nº3, (1995), p205-210. DOI:10.1016/0951-5240(95)00011-H

Hines, P., **Development and Learning in Organizations: An International Journal,** *How to create and sustain a Lean culture*, vol.24, nº 6, (2010). ISSN: 1477-7282

Iami, M., McGraw-Hill Education, **Kaizen: The Key to Japan's Competitive Success** 1st edition, (1986). ISBN 978-0075543329

Junior L, et al., **International Journal of Production Economics**, *Variations of the Kanban system: literature review and classification*, v. 125, nº 1, (2010), p. 13-21. DOI:10.1016/j.ijpe.2010.01.009

Keupp, MM et al. – **International Journal of Management Reviews,** *The Strategic Management of Innovation: A Systematic Review and Paths for Future Research*, vol. 14, nº4, (2012), p. 367-390. DOI: 10.1111/j.1468-2370.2011.00321.x

Kusar, J. et al. – **Journal of Mechanical Engineering,** *Reduction of Machine Setup Time*, vol. 56, nº12, (2010), p. 833-845. ISSN: 2394-6202

LEITE, J., **"F-16MLU - Melhoria da Qualidade do Processo de Modificação".** (Dissertação Mestrado), Instituto Superior Técnico/Universidade Técnica de Lisboa, (2008).

Liker J.K., Bookman, **O modelo Toyota: 14 princípios de gestão do maior fabricante do mundo,** 1st Edition. 2005. ISBN: 978-8536304953

Martínez-Jurado P.J., et al. - **BRQ Business Research Quarterly**, *Human resource management in Lean Production adoption and implementation processes: Success factors in the aeronautics industry*, vol. 17, nº1, (2014), p. 47-68. DOI:10.1016/j.cede.2013.06.004

McIntosh, R., et al. - **IEEE Transactions on Engineering Management,** *Changeover Improvement: Reinterpreting Shingo's "SMED" Methodology,* vol. 54, nº1, (2007), p.98-111. ISSN: 0018-9391, 2007

McIntosh, RI, et al. - **International Journal of Production Research**, *A critical evaluation of Shingo's' SMED'(Single Minute Exchange of Die) methodology*. vol. 38, n. º 11, (2000), p. 2377-2395. ISSN: 0020-7543

Moacir Godinho Filho et al. – **Gestão & Produção**, *Manufatura enxuta: uma revisão que classifica e analisa os trabalhos apontando perspetivas de pesquisas futuras*, vol. 11, nº11, (2004), p. 1-19. ISSN 1806-9649

Monden Y., CRC Press – **Toyota Production System An integrated approach to Just-In-Time**, Fourth edition, (1998). ISBN: 9781439820971

Moxham C., **International Journal of Quality & Reliability Management,** *Prerequisites for the implementation of the SMED methodology: A study in a textile processing environment*, vol. 18, nº4, (2001), p. 404-414. ISSN: 0265-671X

NAKAJIMA, S. ; Association Française de Normalisation, **La Maintenance Productive Totale (TPM)**, (1989). ISBN: 2-12-465111-0

Ohno, T.; Productivity Press; **Toyota Production System: Beyond large scale production**, 1st edition, (1988). ISBN 0915299143.

Pellegrini, S., et al**., Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management Istanbul, Turkey**, *Study and Implementation of Single Minute Exchange of Die (SMED) Methodology in a Setup Reduction Kaizen*, (2012).

Pereira Cabrita, C. ; **Caracterização das filosofias Lean production, six sigma, Lean sigma e Lean Maintenance**, Universidade da Beira Interior, (2009).

Pereira, Ivo – **Central Logistic Report Plan**, (2014).

Pinto, JP., Lidel edições, **Pensamento Lean - A filosofia das organizações vencedoras**, 1st Edition, (2009). ISBN: 9789727576463

Riezebos, Jan - **Computers in Industry**, *Lean Production and information technology: Connection or contradiction?* , vol. 60, nº4, (2009), p. 237-247. DOI:10.1016/j.compind.2009.01.004

Robert K. Yin, Porto Alegre, **Estudo de caso - planeamento e métodos**, 2nd Edition, (2001). ISBN: 85-7307-852-9

S. Sabri et al. - **Proceedings of the Fifth Asia Pacific Industrial Engineering and Management Systems Conference 2004**, *Lean Strategies for furniture manufacturing*, (2004).

Santos J., **Improving Production with Lean Thinking**, (2006). ISBN: 978-0-471-75486-2

Sherali, H.D., Goubergen, D.V., Landeghem, H.V., **European Journal of Operational Research,** *A quantitative approach for scheduling activities to reduce set-up in multiple machine lines*, vol. 187, nº3, (2008), p. 1124-1237. DOI:10.1016/j.ejor.2006.06.068

Shingo, Shingeo; Productivity Press; **A revolution in manufacturing: the SMED system**, 1st edition, (1985).ISBN: 0915299038

Shook, J; Rother, M.; Lean Enterprise Institute; **Learning to see: Value Stream Mapping to add value and eliminate MUDA**, 1st edition, (2003). ISBN: 9780966784305

Sugai, M. et al. **Gestão Produção,** *Metodologia de Shigeo Shingo (SMED): análise crítica e estudo de caso*, vol. 14, nº 2, (2007), p. 323-335. DOI: S0104-530X2007000200010

US Environmental Protection Agency, **Lean Manufacturing and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recommendations for Leveraging Better Environmental Performance**, (2003). EPA: 100-R-03-005

Vieira Conceição, S., et al. **Gestão Produção**, *Desenvolvimento e implementação de uma metodologia para troca rápida de ferramentas em ambientes de manufatura contratada*, vol. 16, n. 3, (2009), p. 357-369. DOI: 10.1590/S0104-530X2009000300004

Voss Chris et al., **International Journal of Operations & Production Management,** *Case Research in Operations Management*, vol. 22, nº2, (2002), p. 195-219. ISSN: 0144-3577

Wambersie A. et al., Springer Berlin Heidelberg, **Symposium on High-Energy Electrons**, *Depth dose curves determined by ionization, film density, and ferrous sulfate and survived rate of coli bacteria and diploid yeast using a 20MeV electron Beam*, (1965). DOI: 10.1007/978-3-642-88334-7_30

Werkema C., Campus editora, **Lean Seis Sigma - Introdução às ferramentas do Lean Manufacturing**,1st edition, (2012). ISBN-10: 85-352-5384-X

Womack J., *"Mura, Muri, Muda?"* (2006).

Womack J.; Jones D.T.; Roos, D.; Rawson's associated, – **The machine that changed the world: The story of Lean Production**, 1st edition (1991). ISBN: 0-89256-350-8