Mestrado em Engenharia e Gestão Industrial

Process Optimization in the Core Manufacturing Department of a Foundry Industry

Relatório de estágio apresentado para a obtenção do grau de Mestre em Engenharia e Gestão Industrial

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"One, remember to look up at the stars and not down at your feet. Two, never give up work. Work gives you meaning and purpose and life is empty without it. Three, if you are lucky enough to find love, remember it is there and don't throw it away."

— Stephen Hawking

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RESUMO

A atual globalização, assim como o aumento da competitividade nos mercados nacionais e internacionais, deu origem a um ambiente imprevisível que levou as organizações procurar soluções para se superarem e procurar melhorar, de forma continua os seus processos produtivos nos ramos em que se encontram inseridas, com o objetivo de prestar um serviço superior e disponibilizar produtos com qualidade elevada e com menos custos associados.

A implementação de metodologias relacionadas com a filosofia Lean tem revelado aumento na competitividade das organizações através de processos de melhoria contínua, para a redução de desperdícios assim como a otimização e normalização de processos e organização dos espaços de trabalho. Este novo paradigma de produção levou a muitas empresas adotar esta filosofia, no entanto a sua implementação nem sempre é bem sucedida. Neste trabalho são identificadas e caracterizadas alguns paradigmas e ferramentas desta filosofia, assim como algumas causas das falhas na implementação.

Esta dissertação surge no âmbito de um estágio numa empresa líder nacional no setor da fundição, com o objetivo de otimizar os processos produtivos no departamento da Macharia através de uma abordagem SMED para redução dos tempos de troca de caixas de machos e TPM para aumentar a produtividade dos equipamentos e colaboradores do mesmo departamento.

Palavras Chave: Implementação Lean, Otimização de Processos, SMED, TPM, Macharia

ABSTRACT

The current globalization, as well as the increase in competitiveness in national and international markets, originated an unpredictable environment that led organizations to seek solutions to overcome and continuously improve their production processes in the sectors in which they are inserted, with the objective of providing superior service and high quality products with less associated costs.

The implementation of methodologies related to Lean philosophy has revealed an increase in competitiveness of organizations through continuous improvement processes, for the reduction of waste as well as the optimization and normalization of processes and organization of workspaces. This new paradigm of production has led many companies to adopt this philosophy, however its implementation is not always successful. In this work some paradigms and tools of this philosophy are identified and characterized, as well as some causes for implementation failure.

This dissertation arises as part of an internship in a leading national company placed in the foundry sector, with the objective of optimizing the production processes in the core manufacturing department through a SMED approach in order to reduce the setup times in the interchange of core boxes and TPM to increase productivity in the equipment and employees of the same department.

Keywords: Lean Implementation, Process Optimization, SMED, TPM, Core Manufacturing

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FIFO	First In First Out
GM	General Motors
HRM	Human Resources Management
IMVP	International Motor Vehicle Program
JIPE	Japan Institute of Plant Engineers
JIPM	Japan Institute of Plant Maintenance
JIT	Just In Time
LM	Lean Manufacturing
MDF	Medium Density Fibreboard
MIT	Massachusetts Institute of Technology
MTS	Make To Stock
NVA	Non Value Added
OEE	Overall Equipment Efficiency
SME	Small and Medium Enterprises
SMED	Single Minute Exchange of Die
TPM	Total Productive Maintenance
TQC	Total Quality Control
TQM	Total Quality Management
TPS	Toyota Production System
TMC	Toyota Motor Company
USA	Unites States of America
VSM	Value Stream Mapping

1. INTRODUCTION

1.1 Foundry Industry

Casting production has been one of the main influencers for the development of world's economy. According to Holtzer and co-workers, the progress achieved over the last few years in foundry engineering has shown a path to further developments of foundry technology. The last decade brought significant changes in the world map for the greatest casting producers (Holtzer, Danko and Zmankowska-Kumon, 2012). Sand casting is the process used to shape molten ferrous metals and non-ferrous alloys, where molten material its drawn by gravity into the mould and then left to cool and solidify. Thompson stated that, because sand casting relies on gravity to draw the molten material into the mould cavity, there will always be an element of porosity in the cast part (Thompson, 2007). To eliminate the roughness of the cast process, products often have to be finished using abrasive materials or machining. The moulds and cores are usually made from sand that is bonded with clay or synthetic materials and pressed into the pretended cavity or shape. Some of the steps involved in the casting process are pattern and core making, moulding, melting and pouring the metal, finishing, cleaning and testing.

The casting process has shown its versatility by achieving complex metal shapes with great durability and a reduced amount of labour involved. Therefore, the resultant products can be found in numerous applications, the automotive industry alone is responsible for half of the world's production, followed by industrial engineering, construction and infrastructures systems, electronics, medical and aviation products. Metal casting foundries became significant consumers of scrap metal transforming obsolete and worn objects into useful new products.

1.1.1 Brief History

Since ancient times foundry has been a part of the human history. Modern civilization would not be as advanced if it was not for the discovery and development of foundry industry and its products. The history of foundry is traced back to the ancient period in which metallic objects in the form of coins, arrows, and household articles were made through melting the metal followed by pouring it into suitable moulds. The foundry history is mainly related to the craftsmen of Greek and Roman civilizations and since then, the role of casting metals acquired unique significance.

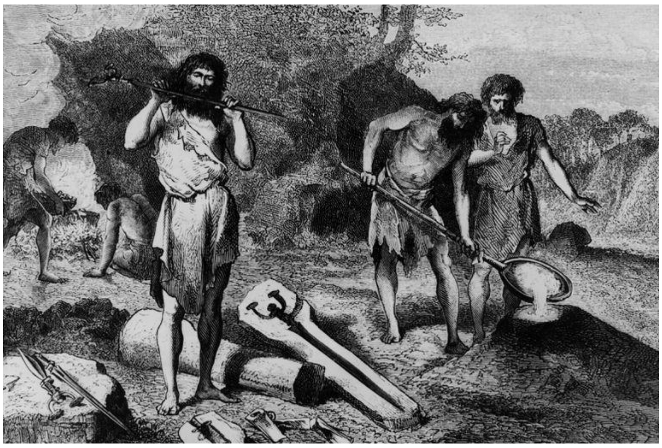

Figure 1.1 – Ancient Casting Process

1.1.2 Estimation of the current situation in world's casting production

The casting production is one of the main factors that impact the development of world´s economy. It is shown that casting production has suffered a substantial growth in the past decade. Despite this, the total production of casting in 2010 (91.4 million tons) was in fact lower than the production of 2008 (93.5 million tons), the highest peak was in 2007, when casting production equalled to 94.9 million tons (Holtzer, Danko and Zmankowska-Kumon, 2012). The world leader in the casting production for many years was China, which produced 43% of the castings in 2010 as it is shown in Figure 1.2. The EU countries share in the casting production corresponds to approximately 15 %. India presents a smaller production, with a share of 10%.

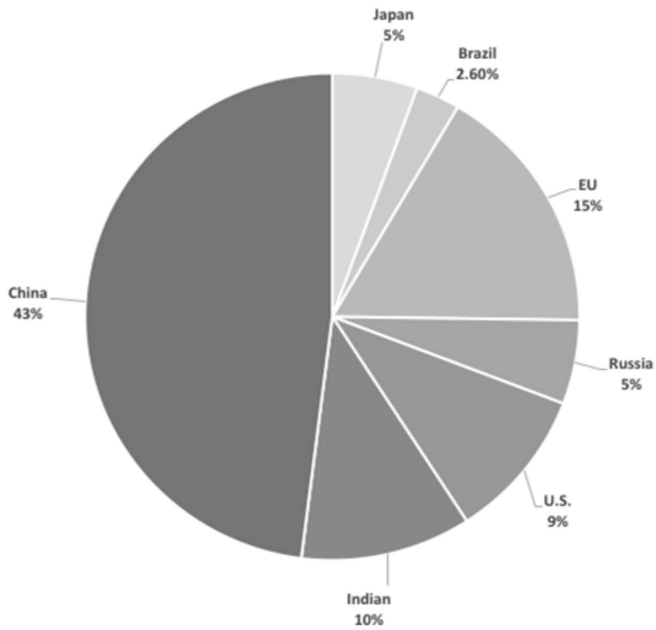

Figure 1.2 – Leading countries share in world casting industry. Adapted from: Holtzer, Danko and Zmankowska-Kumon, 2012

The European foundry industry is the third largest in the world in the casting of ferrous metals and the second largest for non-ferrous metals. France, Italy and Germany are the countries with the highest production in Europe, each one with a total annual production of over two million tons of castings. The highest fraction of casting production is constituted by grey iron castings, with approximately 48% of the total. Castings of spheroidal cast iron represent nearly 25% and the segment of steel casts corresponds to approximately 11%. The non-ferrous metals castings are dominated by aluminium alloy casting, with approximately 11% of the total world casting production. The percentage of magnesium, zinc, copper is very small (Holtzer, Danko and Zmankowska-Kumon, 2012).

Figure 1.3 shows the most significant markets that foundry industry serves. Automotive industry, mostly in the field of motorization is the biggest market server by this industry, with a share of 50%. Engineering industry is the second sector with most use of casting manufactured products with 30%, general engineering and construction sectors have the lowest share in this market (J.Danko and M.Holtzer, 2006).

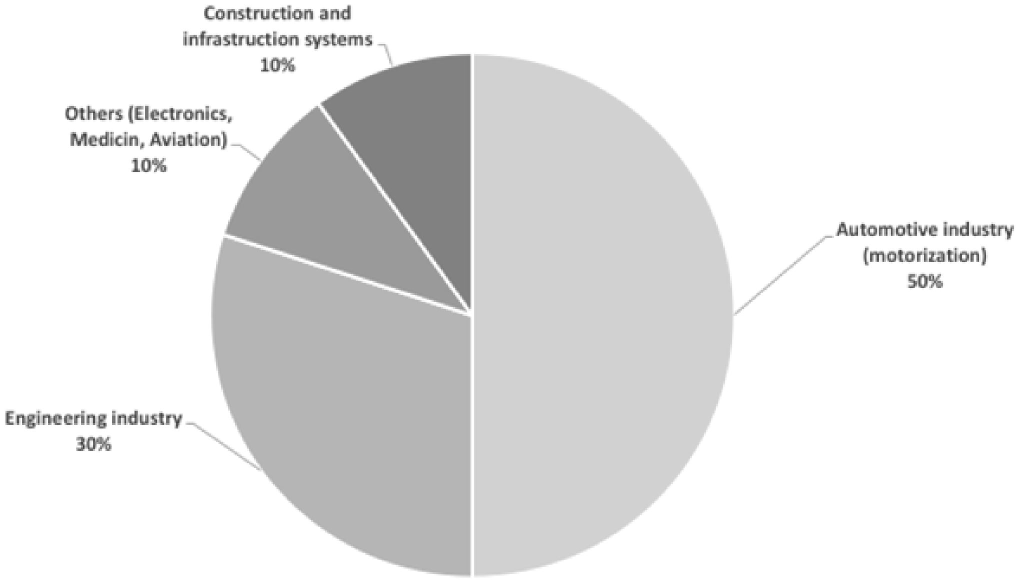

Figure 1.3 – Main markets served by foundry industry. Adapted from: Holtzer, Danko and Zmankowska-Kumon, 2012

1.2 Fucoli - Somepal, Fundição de Ferro, SA

Fucoli – Somepal Fundição de Ferro, SA it's a Portuguese group with two units located in Coimbra and Pampilhosa dedicated to the production and commercialization of cast iron products for the water and sanitation segment. With several decades of experience in the development and manufacture of its products, Fucoli – Somepal has reached a solid position in the market where good service to its customers, the quality of the products and the compliance of delivery dates are embedded in the company's policy.

The company was created in 1946 with the birth of Fucoli – Fundição Conimbricense, Lda in Coimbra, but only in 1949 started the manufacturing of products for the water and sanitation sector. Some years later, in 1957 Somepal – Sociedade Metalúrgica da Pampilhosa, Lda is founded to manufacture several types of valves. In 1990 Fucoli, Lda acquires the share capital of Somepal, Lda, and performs relevant investments and modifications in order to secure the quality-price ratio.

The manufacturing line is modernized and a quality system is implemented. The NP EN ISO 9002 was granted in 1994 for the Mealhada unit and, in 1996, to the Coimbra unit. It was not until 1998 that the merge between Fucoli – Fundição Conimbricense, Lda and Somepal – Sociedade Metalúrgica da Pampilhosa, Lda took place providing a larger production scale for both clients and suppliers. The company then adopted the designation Fucoli – Somepal Fundição de Ferro, SA. Since the date of the merge, several investments were made regarding equipment and the facilities, thus modernizing the production process. In 2005 the cupola furnace was replaced by an electric unit providing more efficiency and less environmental impact.

The Pampilhosa unit has been progressively increasing its covered area and modernizing the equipment associated with the process of finishing parts, with the purchase of a painting robot and installation of new CNC devices. In 2009 Fucoli – Somepal, SA acknowledged, in its Coimbra unit, the certification of its environmental management system. Since 2011, the company has implemented Lean manufacturing methodologies in the production and organizational processes to ensure high quality standards and a fast response to its client's needs. In 2017, a runner smasher equipment was acquired to improve the melting process time, and two smart storage systems were installed to store the core boxes and the grinding tools for the finishing processes. Figure 1.4 shows some of the key moments of the Fucoli – Somepal Group.

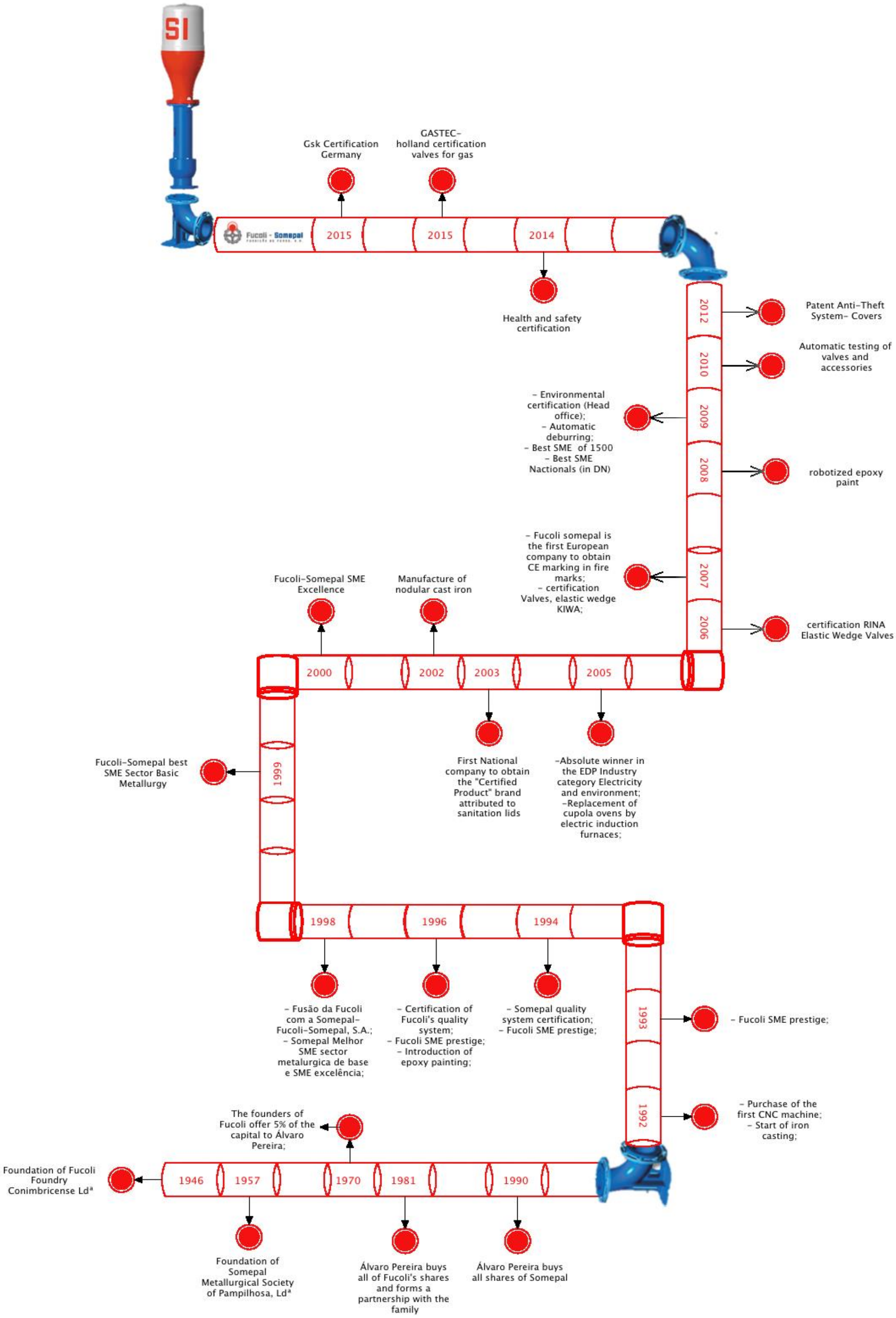

Figure 1.4 – Key moments of Fucoli – Somepal

Among the two production units the company employs around 200 people and the annual production is around 15000 tons, about 50% is dedicated to exportation. The products are manufactured with high quality standards and homologation for several international entities such as CERTIF in Portugal, AENOR in Spain, KIWA in The Netherlands and RINA in Italy. CE Marking is applied to products when required by legislation. Fucoli – Somepal also holds the NP EN ISO 9001 certification in both units and NP EN ISO 14001 certification in the head office.

1.2.1 Organization and Products

Fucoli – Somepal, SA. has two industrial facilities located in Coimbra, and Mealhada (in the civil parish of Pampilhosa). The company is internally divided in departments that work together with the purpose of obtaining the best final product. There are different sectors among the headquarters facilities and the branch office; hence some stages of the productive process can only be completed in one of the production units. Figure 1.5 shows the organization of both production units.

Although, both facilities hold the equipment to accomplish most of the productive processes to reach the final products on its own, the production system is distributed between the two facilities. The headquarters is responsible for the entire production of cores used in the foundry process in both facilities, the manufacturing of most of the foundry products, grinding and painting the most demanded and smaller size products. It is also where all the moulds are created, maintained and stored. The branch office is mainly responsible for grinding and refurbishment processes using CNC equipment, the manufacture of larger foundry pieces plus all the products that have a consumption of less than 20 units per year, the design and production of some core boxes, assembly and testing products plus the epoxy paint process.

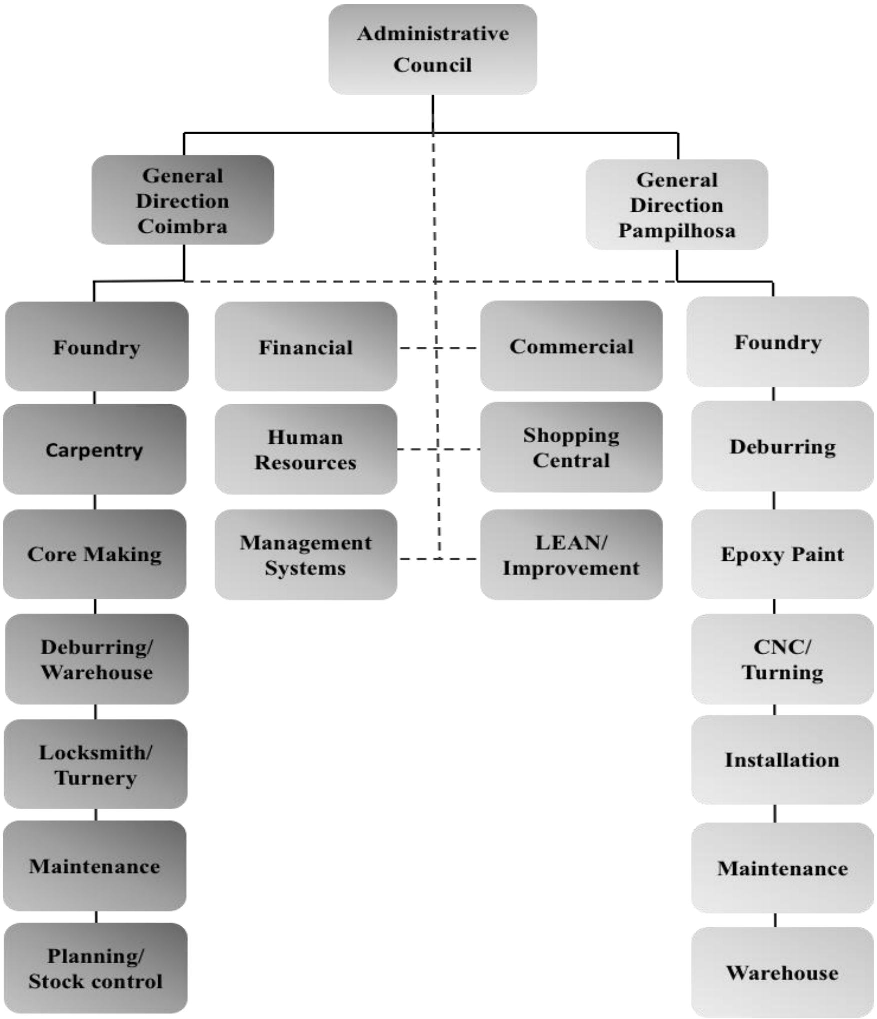

Figure 1.5 – Organizational Structure of both facilities

Fucoli-Somepal´s products are manufactured in a material known as nodular cast iron. Cast iron belongs to the family of ferrous alloys with a large variety of proprieties. It can be casted in the desired shape instead of being worked in the solid state. Unlike steels, that normally contain less than 1% of carbon contents, cast iron generally possess 2% to 4% of carbon and 1% to 3% of silicon. Other nodular elements might be present, allowing to control or modify certain proprieties.

Cast iron can be distinguished in four types or different categories, according to the distribution of the carbon in the microstructure, as shown in Figure 1.6: grey, ductile, white and malleable. Ductile or nodular cast irons also known as cast iron with nodular or spheroidal graphite, are the ones that Fucoli-Somepal is currently manufacturing.

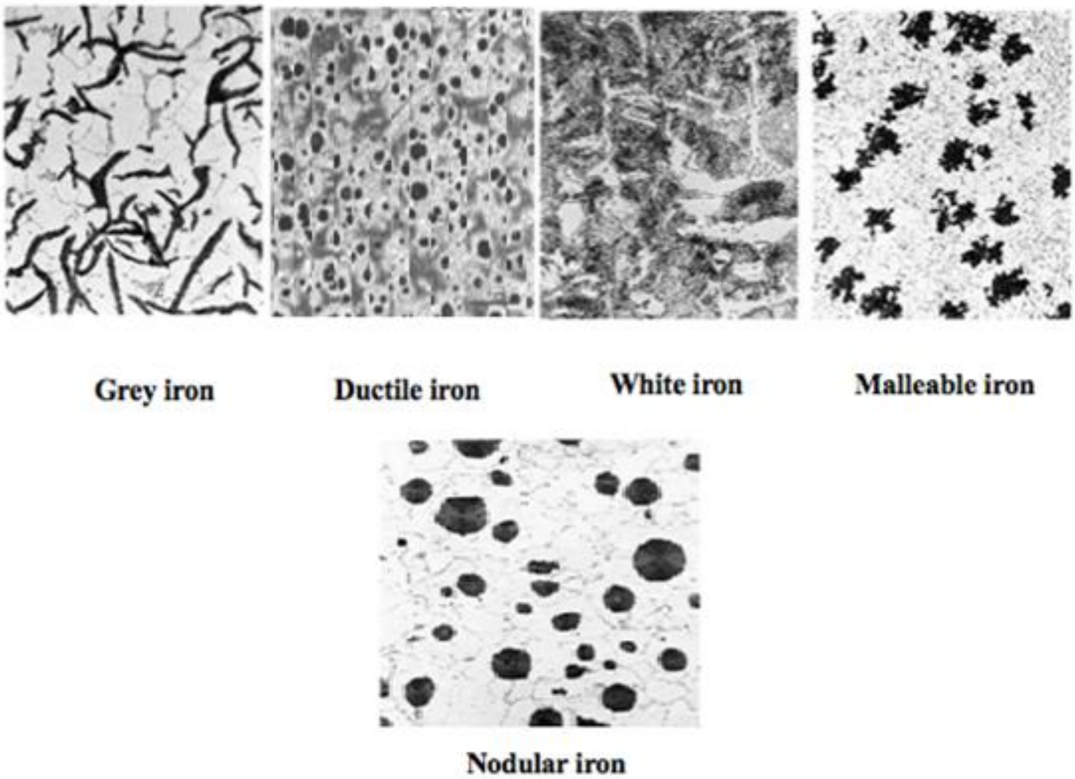

Figure 1.6 – Categories of cast irons

Ductile cast iron presents a good fluidity, good leakage suitability, excellent machining ability and decent resistance to wear. Additionally, ductile cast iron has similar proprieties to steels, like high mechanical resistance, tenacity, ductility, hot deformability and temperability. Due to the presence of graphite spherical nodules in the inter structure, these irons have exceptional engineering properties, as seen in Figure 1.7. The existence of a relatively ductile matrix between the nodules tolerates significant deformation without the occurrence of fracturation.

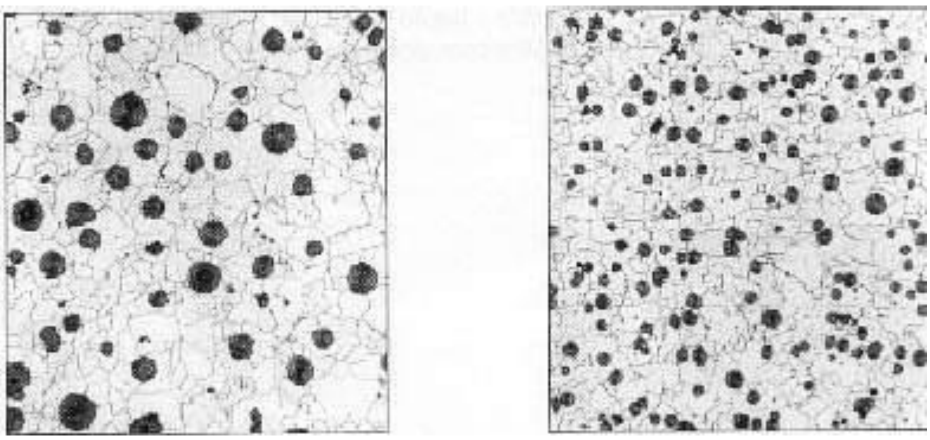

Figure 1.7 – Microstructure of nodular cast iron

The non-bonded ductile cast iron contains a content of carbon that fluctuates between 3% to 4%, and the content of silicon fluctuates between 1.8% and 2.8%. Other impurities should be kept at low levels, since they are able to interfere with the formation of graphite nodules in the ductile cast iron. At this time, the activities developed by the company are focused in the production of materials associated to water and sanitation, gas and telecommunications sectors. The range of products manufactured at Fucoli-Somepal, SA are shown in Figure 1.8.

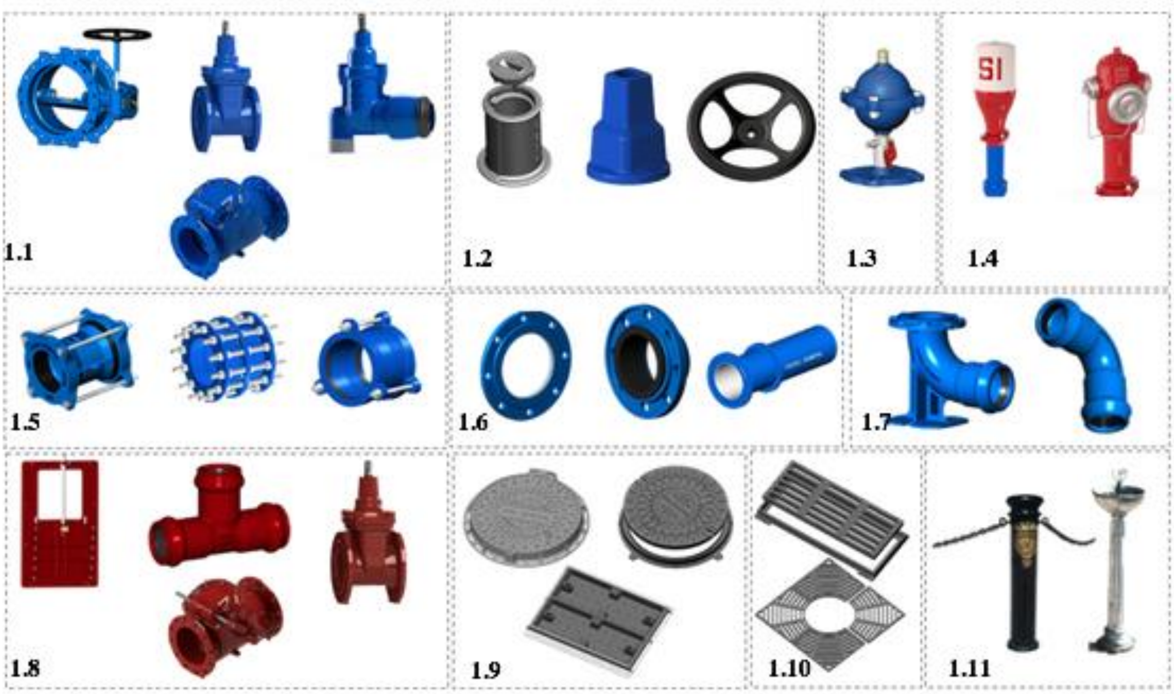

Figure 1.8 – Categories of products produced in Fucoli-Somepal, SA: 1.1 - Valves (soft sealing gate valves, Service Connection Soft Sealing Gate Valves, check valves, other valves; 1.2 - Valve accessories; 1.3 - Air valves; 1.4 - Fire Hydrants; 1.5 - saddles and joints; 1.6 - Flanges and pipes; 1.7 - Ductile iron fittings; 1.8 - Valves and fittings for residual use; 1.9 - Manhole covers; 1.10 - Gully great; 1.11 - Sight furnishings

The products manufactured at Fucoli-Somepal are nearly 100% recyclable and there is no prediction of ambient impacts associated with its use during the entire life time.

1.2.2 Markets

Half of the products manufactured and commercialized by Fucoli – Somepal go to internal markets, where the main customers are city councils, municipal services, civil construction companies, warehouses, public works and other industries. The remaining 50% percent are exported to external markets, as shown in Figure 1.9 and Table 1.1, to several countries, in four continents, such as Europe, Africa, America and Asia.

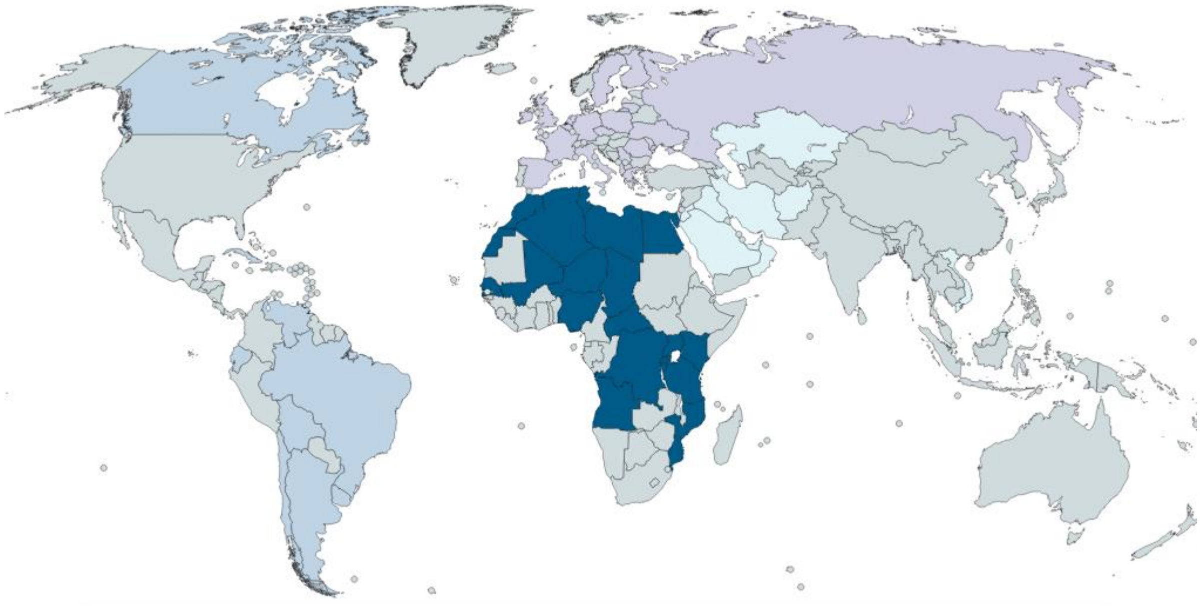

Figure 1.9 – Markets

Table 1.1 – Countries affiliated with Fucoli – Somepal

Europe	Africa	America	Asia
Germany	Angola	Argentina	Afghanistan
Belgium	Algeria	Bolivia	Saudi Arabia
Croatia	Burkina Faso	Brazil	Azerbaijan
Denmark	Burundi	Canada	Kazakhstan
Spain	Cape Verde	Chile	United Arab Emirates
Finland	Chad	Cuba	Iraq
France	Ivory Coast	Ecuador	Israel
Greece	Egypt	Jamaica	Jordan
Netherlands	Guinea-Bissau	Uruguay	Kuwait
Ireland	Libya	Venezuela	Macao
Italy	Mali		Oman
Lithuania	Morocco		Qatar
Luxemburg	Mozambique		Sri Lanka
Moldavia	Niger		Vietnam
Poland	Nigeria		Lemm
UK	Kenya		
Romania	Central African Republic		
Russia	Democratic Republic of Congo		
Czech Republic	Senegal		
Serbia	Tanzania		
Sweden	Tunisia		
Switzerland	Uganda		
Ukraine			

1.2.3 Productive Process

Carpentry:

- The productive process of Fucoli – Somepal begins in the carpentry. It is the department where moulds are designed, prepared and some of the core boxes are manufactured. In terms of geometry, the mould is similar to the cast iron piece intended to be produced. The mould is 1% larger than the cast iron piece because of the contraction suffered during solidification. Moulds can be produced in resin, wood or aluminium. Aluminium moulds are used when regarding high demand products in order to prevent wear in the mould and also when the goal is to achieve a superior superficial finish of the cast product. The mould plates are numerically identified and stored in racks, as well as the negatives and core boxes.

Core Manufacturing:

- The production of the core boxes is related to the production of the necessary elements to create hollow products. Among the headquarters and the branch office, the company has five equipment that allow the production of cores in different sizes. The process used to achieve the production of cores is known as the cold box method, where sand is mixed with resins that act as binders, pressurized into the core boxes and then hardened with a catalyser that accelerates the resin reaction. After the mixture of sand and binders is pressurized into the core boxes, hardening of the core is achieved by gassing the curing agent, into the core boxes at room temperature. Subsequently, dry air is conducted through the core box to perform a washing step, therefore allowing the demoulding of the core.

  After the cores are extracted, the next procedures are final touches, where burrs are trimmed to correct any defects and painted is applied, when necessary. The painting operation allows an improvement in the superficial finish of the casted product.

Foundry:

- The moulding process used is known as green moulding, and the main components are:
  - sand of appropriate grain size and shape;
  - binders in the form of clay, namely bentonite;
  - additives, such as coal dust;
  - water that is added in certain amounts, according to the desired properties.

In the headquarters, the components mentioned above are stored in silos and then routed to a mixer. This process is entirely autonomous, the added quantities of each element are monitored and defined through a computer controlled system. The prepared sands are then fed to the forming machine. In this equipment sand is weighted regarding the product that is being manufactured at the moment.

Each moulding box is obtained while putting together two half mouldings boxes, the mould plate will be sequentially pressed into the bottom and top half's. Sequentially, the half mouldings move to the station where placement of the cores occurs. The half-moulds are then overlapped following to the metal pouring section. In the headquarters, the raw materials are stored in pits ant then extracted using electromagnets that are linked to a weighing system.

The operator weights materials, according to the defined instructions, and a procedure is monitored for the addition of each component. The casting returns are the runners and all the defective parts that are not able to be re-worked. At the headquarters there are two half ton furnaces that have the ability to produce four tons per hour, while one of them contains the melted iron ready to be poured; the other one is in the process of melting, allowing flow of the operations without stoppage times due to the iron not being ready to pour. The liquid metal is then inserted into an automatic casting system and poured into the moulds. In the branch office the pouring is performed manually.

After casting, the moulds are transported to the crushing area during a period of approximately one and a half hours, which allows the cooling to room temperature. In the crushing zone the non-used pieces are removed from the moulding boxes trough vibration, plus the sand is collected and re-routed for later reuse.

Shot blasting:

- After crushing, the remaining pieces are introduced in baskets and then transported to the blasting machine. In this device, the casting pieces are hit with small metal spheres that remove excess sand from previous procedures.

Grinding:

- After the parts are clean, the burrs are removed using different equipment, depending on the type of product and the necessary finish, such as:
  - automatic Grinding Machines;
  - angle grinders.

In the headquarters, the pieces that are painted black are sent to the immersion painting system. The rest is sent to the storage area for later shipment to the branch office.

Machining:

- The machining process is understood as the one that provides the desired shape, size and finish. This sector is equipped with CNC machines to guarantee great quality and reliability of the final products.

Epoxy painting:

- At this stage the painting of the pieces is carried out, mostly in blue. This consists on the application of a layer of uniform paint on the whole exposed part of the piece in order to prevent corrosion formation during the whole life cycle of the product.

Assembly and testing:

- In this department the technical specifications of the respective products are available and all parts are assembled and submitted to hydraulic tests, in order to check their strength and tightness.

1.3 Paperwork Goals

This work was developed in the scope of the Master's Degree in Industrial Management Engineering, to describe the various functions integrated throughout the internship. The dominant goal was process optimization in order to reduce setup times of the core manufacturing boxes and improve overall efficiency of the core manufacturing department. It was also attempted the implementation of an autonomous maintenance plan in the core manufacturing equipment, considered the bottleneck of the operation and standardization of procedures to increase productivity among employees related to the same equipment.

1.4 Work Structure

Regarding the structure of this work, it is divided into five chapters. In the first chapter a perspective on foundry industry is created, followed by the presentation of the company where the work was performed, emphasizing the type of products manufactured, the productive process and the markets that its inserted. This chapter is closed with the aim of this work and its structure. The second chapter includes the literary revision of the fundamental topics for the accomplishment of this work, such as Lean Manufacturing, some of its tools and the difficulties that Small and Medium Enterprises (SME) face when implementing these techniques. SMED and TPM are mentioned as the main tools used during this project at Fucoli – Somepal, SA. In the third chapter the experimental work and the knowledge acquired in the core manufacturing department during the internship is stated. The discussion of the work accomplished is defined in the fourth chapter. Finally, the fifth chapter regards the conclusions of the presented work and proposes future projects.

2. STATE OF THE ART

2.1 Lean Manufacturing

During the 21st century, industries all around the world are constantly struggling with their shareholders in order to increase the productivity at their production units. In a reality where competitiveness is huge, not only between organizations in the same field of business, but also between manufacturing units in the same group, the producers keep looking for possibilities to increase the efficiency of their production processes therefore its competitiveness (Carvalho, 2006). The intensification of globalization means that is necessary to evaluate the markets in a global perspective, where SME's compare themselves with organizations worldwide and, also, world class performance becomes the goal for those manufacturing organizations (Soltan and Mostafa, 2015). As markets keep shifting, meeting the challenges of worldwide competition between manufacturers requires a bundle of practices. Such goals can be achieved through diverse methods, such as the purchase of new technology, enhancement of services, quality improvements and waste reduction (Pech e Vaněček, 2018). Therefore, Lean Manufacturing (LM) is a common practice among organizations in order to achieve the desired performance for its production units. In 2014, Mahmood stated that Lean represents more than its tools, that it is a philosophy and its implementation is a long term approach where organizations need to, continuously, place efforts in order to achieve significant improvements (Mahmood, 2014).

2.1.1 Brief History of Lean Manufacturing

Lean manufacturing methodologies are related to the automotive industry since its early stage: the first vehicles were produced with low efficiency and excessive costs meaning that they were not available for the average citizen (Makhomu, 2012). Henry Ford was aiming to expand the availability of the car to a wider range of consumers, something that would only be possible through the reduction of the production costs hence reducing the price of sale price. Ford recognised these limitations and changed the industry's standards through the development of numerous techniques that currently would be associated with Lean manufacturing. These techniques led to the introduction of the moving assembly line, which, according to Womack and Jones, is the basic premise for what nowadays we call a continuous flow production system (Womack, J.P. and Jones, D.T. 2003).

Ford Motor Company was growing gradually and, in Japan, the autonomous mechanical loom was introduced by Sakichi Toyoda in 1918. Toyoda Automatic Loom Works was later established, in 1926. Following the creation of Toyoda's company, his son Kiichiro, travelled to the United States of America (USA) where he had the opportunity to connect with the automotive industry and gained great interest due to the innovative character that it represented. The proceeds from the sale of the patent related to the loom allowed the creation of a vehicle department at the current company and, in 1937, Toyota Motor Company (TMC) is established, in a market entirely dominated by Ford and General Motors (GM) (Holweg, 2007). Due to the short volume of sales after the second World War, Kiichiro was replaced by Eiji Toyoda, its cousin, and, in 1950, Eiji travelled to the USA to study the western production methods in order to implement them in the family's company. The solution offered by Toyota led to the complete renovation of the company and gave birth to the introduction of an alternative production system. In result of the western journey, and having Taiichi Ohno as its mentor (Figure 2.1) the Toyota Production System (TPS) was introduced.

Figure 2.1 – Taiichi Ohno, the mentor of TPS

Ford and GM's production systems were based in mass production, relying on economies of scale and large equipment to produce the largest amount of parts as affordable as they possibly could. Meanwhile the Japanese market, after the second World War was small; therefore, Toyota was forced to create several type of vehicles in smaller quantities with the same manufacturing process to satisfy its consumer's needs (Simões, 2008).

The main differences between the American and Japanese production systems are presented in Table 2.1. By highlighting Just-in-Time (JIT) production and Total Quality Control (TQC), lead times were reduced and the production lines were kept flexible. The TPS was adopted by many Japanese manufacturers, which provided them a distinct competitive advantage, related to western ones (Simões, 2008). According to Cusumano, in the late 80's, the output per worker was two to three times higher than in the US or European plants (Cusumano, 1994).

Table 2.1 – Comparison between Toyota and Ford's production system

	Lean Production	Mass production
Company	Toyota	Henry Ford
Equipment	❑ Automatic and manual systems that allow big volume productions with high variability of products relating to the clients demands	❑ Expensive and oriented to a single function
Philosophy	❑ Search for perfection	❑ Sufficient quality
Organizational Philosophy	❑ Delegation of responsibility	❑ Responsibilities related to management
Production Methods	❑ Production according to the clients demands	❑ High volumes of standardized products
Contributors	❑ Teams of multi skilled professionals in all the levels of the organization	❑ Low qualified professionals

As mentioned above, Lean production is related to the TPS, and the general idea behind the TPS is to produce the kind of units needed, at the time needed in quantities such, that unnecessary intermediate and finished product inventories can be eliminated. According to Pettersen, the basis of the TPS is the absolute elimination of waste and the two pillars that support the TPS are JIT and Jidoka or *autonomation* (Pettersen, 2009). The bundle of tools and principles associated with the TPS methodology are represented through the TPS temple, in Figure 2.2.

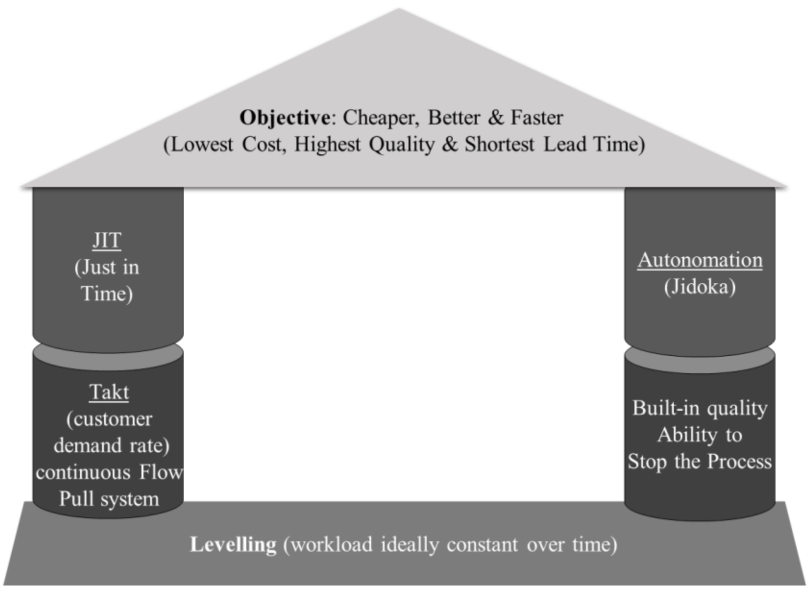

Figure 2.2 – TPS Temple

JIT expresses that nothing should be produced, transported or bought before the need appears, therefore avoiding waste. Jidoka states that during the occurrence of anomalies, the production could possibly be interrupted in an autonomous way, assuring the quality of the entire process. The fundamental objective of the TPS is represented in the top of the temple, i.e., to achieve an growth in productivity and efficiency by avoiding waste, as in an industrial environment, waste may represent about 60% of the total value chain (Hines, P., Taylor, D. 2000).

The term “Lean” was introduced by Krafcik, in 1988; at that time, the leading researcher in the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT). Since it was pioneered by Toyota, Lean production has evolved and has been widely adopted by many organizations around the world in numerous forms and several designations. Today, it still is one of the most promoted and competitive management models in use. The current interest in Lean represents the industrial and service organizations validation of its applicability, as Lean methods are, nowadays, also applied in hospitals, insurance companies and financial services, plus can be beneficial in order to improve productivity in services with an appropriate approach in which customer satisfaction must be considered.

Although, the trend of Lean implementation continues; it is a reality that its success rate is low, namely because of the numerous obstacles faced by the organizations, that are challenging to overcome. Unfortunately, there is no recipe that can assure a successful implementation. Also, unsuccessful implementation can take a great impact on the organization’s resources and affect employees and their confidence in Lean philosophy (Almanei, Salonitis and Xu, 2017).

2.1.2 General Concepts, Principles and Waste

Lean Production or Lean Manufacturing, is a long-term organizational culture that focuses on eliminating waste with the goal of increasing productivity by doing more with less resources, that is, more quality that best serves the demand of customers with less human effort, time, materials and space (Austin, 2013). Krafcik in 1988 mentioned Lean as a manufacturing approach that compared to mass production uses less of everything: half the human effort in the factory, half the manufacturing space, half the investment in tools, and half the engineering hours to develop a new product in half the time. Also it requires keeping far less than half the needed inventory, resulting in fewer defects, and producing a greater variety of products (Krafcik, 1988).

LM achieved a major expansion since Womack and its co-workers released the work “The Machine That Changed the World”, in 1990, based on the TPS, JIT and all its core characteristics (Olhager and Prajogo, 2012). LM is a methodology that involves the simultaneous use of several techniques and tools. Four bundles of related and consistent practices are used, JIT, Total Quality Management (TQM), Total Productive Maintenance (TPM) and Human Resources Management (HRM) (Shah and Ward, 2003). The Lean task is to have the shortest lead time possible, optimum level of strategic inventory, higher customer service levels, higher quality and lowest waste throughout the entire supply chain, in order to win the marketplace (Juran and De Feo, 2010).

According to Womack and Jones, Lean thinking is transversal and suited to be applied, not only in industries, but also in services, construction, projects, consulting, among others (Womack and Jones, 2003). Therefore, there are five fundamental principles to define Lean methodology, as the Table 2.2 shows.

Table 2.2 – Five fundamental lean principles

1. Identify value from customer point of view	Meaning that companies need to identify and initiate product design and manufacture by focusing on the needs of their customers.
2. Value Stream Mapping (VSM)	The principle of VSM is to identify all the steps in the value stream for each product family, eliminating every step, action and practice that does not create value. Value is added to a product when the work is done on the piece; non-value adding steps are represented when the product is waiting in batches or stocks, which is considered waste.
3. Create Flow	This principle describes that is imperative to transfer the product through one value adding step to the next one and keep the production in a constant flow. Organizations must avoid batches and queues or, at least, continuously reduce them and not once interrupt a value adding step by a non-value adding step.
4. Establish Pull	Pull means meeting consumer’s rate of demand with production without reaching overproduction. Most organizations will have to push a certain point and response to a final costumer from that point. The idea is to push this point as long upstream in the manufacturing process as possible, waiting for the demand and then create the product as fast as possible and with high quality as possible.
5. Seek Perfection	As value is specified, value streams are identified, wasted steps are removed, flow and pull are introduced; then, the process starts a new cycle and continues until a state of perfection is reached, in which perfect value is created with zero waste.

Professionals who think Lean, are always aiming for perfection and, performing the improvement cycle is a never ending process, leading to continuous improvements that cover all the aspects at the improvement level, as shown in Figure 2.3.

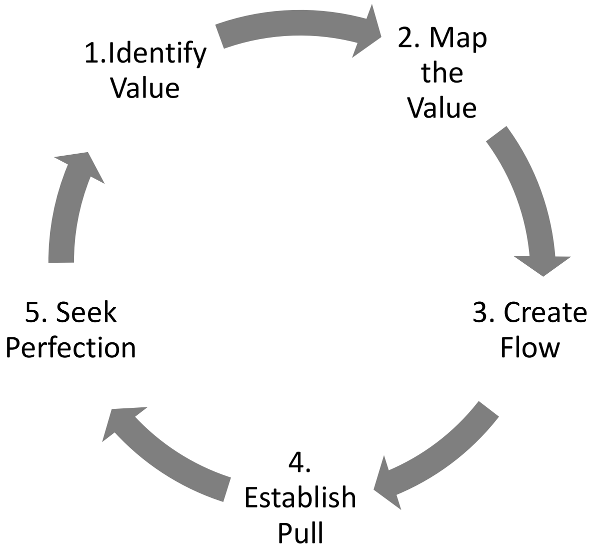

Figure 2.3 – Continuous Process Improvement

Although, Lean does not produce immediate results; the full benefits come only when it becomes the basis for a process of continuous improvement able to keep the results over time. For many companies, namely the process industries, this culture transformation is the hardest change they must reach. However, for assured sustainability the organizations that are truly Lean, will invest the time and efforts to support a change in their culture.

Across this document, we determined that the main goal of Lean implementation is the reduction of waste. According to Soltan and Mostafa, waste elimination refers to eliminate Non-Value Added (NVA) activities from the supply chain and that NVA's depend on the activities performed by the organization (Soltan and Mostafa, 2015). In fact, due to the lack of space and natural resources, Japanese developed repulsion to waste. Therefore, Lean is a philosophy dedicated on identifying and eliminating waste throughout a product's entire value stream, extending, not only within the organisation, but also along the entire supply chain (Schroeder, 2008). In the book titled "The Toyota Way", Liker demonstrated that waste can be categorized into eight different types:

1) Overproduction
    - Manufacturing products or providing services, for which there are no orders, leading to unnecessary storage, staffing and transport costs (Liker, 2004);

2) Waiting
    - Having people stand inactive for long periods and waiting, for different reasons, like the next processing step, equipment downtime or refiling stocks (Liker, 2004);
3) Unnecessary Transportation
    - This type of waste relates to all type of transportation that is pointless. Examples of this could be transporting work in progress through long distances or moving materials into or out of storage between processes (Liker, 2004);
4) Over Processing
    - Processes can be inefficient due to taking unnecessary steps in order to produce a piece or by having a poor product design. Also providing a higher quality than necessary will create waste (Liker, 2004);
5) Excess Inventory
    - Normal effects of having excess inventory include longer lead-times, higher transport and storage costs. Another problem with inventories is that they tend to hide problems such as production imbalances, equipment downtime and long setup-times (Liker, 2004);
6) Unnecessary Movement
    - This waste includes all types of movement needed for the employees to perform their work. An example could be reaching for parts or tools due to lack of organization in the work station (Liker, 2004);
7) Defects
    - Producing defect parts is the most common form of waste; it leads to wasted time on fixing, re-working and manufacturing replacement products (Liker, 2004);
8) Unexploited Employee Creativity
    - Employees can and should be used as more than workforce. They should be encouraged to use their creativity to find improvement ideas and solving problems; not doing so, it is wasting the available knowledge (Liker, 2004). One of the reasons for this to happen is poor task delegation by the leaders.

Lean implementation techniques are one of the most significant paradigms in manufacturing, from its narrow definition around shop floor improvements to a strategic value proposition. The ultimate goal of a Lean operation is to achieve a system that matches supply to customer's demand in a continuous flow.

2.1.3 Lean Implementation Challenges in SME's

Lean implementation has become an ongoing trend in the past years; many organizations with industrial profiles, plus all kind of service businesses, adopted Lean principles expecting to achieve some kind of improvement in the service provided to their customers. However, it can be demonstrated that failure among these projects often occurs due to practical difficulties applying these principles. The transformation process to Lean manufacturing systems requires plenty of effort and participation from all the evolved, from the introduction of new principles in the shop floor to the organizational culture and structure (Simões, 2008).

According to Kotter only 30% of all programs started are successful; some years later, LaClai and Rao demonstrated that 58% of change initiatives failed to reach its expected return; Eaton presents even more radical figures, showing that 75% of the change programs eventually fail (Kotter, 1996) (LaClai and Rao, 2002) (Eaton, 2010). According to Baker's research, the success rate in SME's is as good as 10% on all the initiated programs (Baker, 2002). In Europe, only the SMEs represent 99.8% of all organizations and 67.1% of the employments in the private sector, a figure that rises to further than 80% for industrial businesses (Moeuf *et al.*, 2016).

Numerous Lean implementation methods have been developed for mass production systems (Mostafa, Dumrak and Soltan, 2013); although, this paradigm changes when we mention SME's as they present dissimilar characteristics when related to larger companies, where productivity has been increased to as high as 40%, overall defects reduced by 20% and 50% reduction on lead times (Panizzolo et al, 2012). Several characteristics have been associated to SME's, such as local management, short term strategies, absence of expertise, malfunctioning organization, limited resources and nonexistence of methods and procedures (Garengo, Biazzo and Bititci, 2005). Womack and colleagues claimed that Lean production is valid in all companies, despite their size (Womack, Jones and Roos, 1990); however, more recent works have shown that size of the company is an significant factor in the successful implementation of Lean (Yang, Hong and Modi, 2011).

In the bibliographic references is usual to find information about successful attempts to implement Lean manufacturing rather than implementation failures. Often, these reports are kept confidential because organizations are willingly to protect their failed investments due to the costs acquired. While this happens, it is a reality that these implementations do fail and there are common causes such as Lean suppliers, leadership, involvement of the employees, lack of tools and procedures and business structure (Almanei, Salonitis and Xu, 2017).

Many organizations improve their processes immediately after implementation of Lean methodologies, but fail to sustain the high standards required to keep the momentum going and many times end up backsliding to old habits, a common failure reason leading to the lack of positive outcomes (Awad, 2010). Kumar and Kumar demonstrated that the absence of necessary resources such as labour, capital or communication incapacitate the successful implementation of Lean manufacturing methodologies (Kumar and Kumar, 2014). According to Liker, one of the aims of lean manufacturing is to delegate a greater number of responsibilities to the operational staff, which conflicts with the power of the chief executive; therefore, the lack of delegation in SME's prevents employees from improving their skills, plus the involvement of the chief executive in every operational decision leads to the employee's short term vision of the possibilities (Liker, 2006).

Many organizations attempt to introduce Lean methodologies relying on consultants; so, the resources and quality of the consultants are also a key aspect for a successful implementation. The lack of knowledge and resistance to change by the employees is a huge and usual barrier as well, as the toughest part is the change in habits of the people in the organization specially employees that have been performing the same job in a certain way for many years. It is important to focus in identifying the critical success factors in order to overcome the barriers for the implementation of Lean manufacturing. They summarize into organisational culture, developing organisational promptness, managing commitment and capability, providing the necessary resources, external support from consultants, effective communication, a strategic approach to improvements, teamwork to set realistic timescales for change and to make effective use of commitments and enthusiasm for the transformation (Almanei, Salonitis and Xu, 2017).

2.1.4 Lean Manufacturing Tools

Several tools and techniques are used in the implementation of Lean manufacturing within organizations; as stated earlier in this document, these tools have the primary goal to eliminate waste and promote a growth in the productivity and efficiency of the productive processes. The implementation of these tools and techniques also makes manufacturing cost-effective, enables substantial reduction in manufacturing lead times, leading to a competitive advantage among other companies, therefore maximizing profit. Common tools and techniques are mentioned below.

- 5S
    - Eliminates waste related to poorly designed work stations. The 5S's are Sort, Set in Order, Shine, Standardize and Sustain;
- JIT
    - Just In Time production provides the right part at the right place at right time. It is a methodology that aims to reduce constrains in the production system, and to reduce response time from suppliers and for customers;
- Kaizen
    - Continuous improvement, in order to get suggestions from every organizational level, to keep improving the productive process and promote continuous elimination of waste;
- Kanban
    - A card based system that specifies when and where materials are needed, in order to promote a superior flow internally and externally;
- Single Minute Exchange of Die (SMED)
    - Techniques used to reduce setup and changeover times;
- Standardized Work
    - Good practices to make documented procedures;
- Takt Time
    - Provides a consistent and intuitive method of pacing production and efficiency goals. Represents the rate of customer demand to produce goods and services;

- Total Productive Maintenance (TPM)
    - It's a proactive approach to increase productivity and Overall Equipment Efficiency (OEE) of equipment;
- PDCA (Plan, Do, Check, Act)
    - A continuous improvement approach in a cycle.

The tools and techniques presented are not the only ones related to the implementation of Lean manufacturing in enterprises, there are others that include different approaches. However, in this document, SMED and TPM are highlighted in the next topics as they were the basis to the work performed, during the past year, at Fucoli – Somepal.

2.2 Single Minute Exchange of Die (SMED)

The change of products, tools or adjustments made during the productive processes performed by any type of organization are mentioned as setups or changeover. During the setups, the processes do not create value; additionally, the cost increases and production time decreases. When the costs or setup times are high, companies often choose production in larger batches; therefore, the investment in inventories is substantial. Reducing setup times will help in savings and enables the possibility of producing in small quantities (Sabadka, Molnar and Fedorko, 2017).

2.2.1 Origin and Historical Background

Single Minute Exchange of Die is a popular Lean manufacturing tool established by Shigeo Shingo during the 50's and 60's decades. This method took Shingo 19 years to develop and embraced three crucial moments. It began in 1950 when Shingo conducted a study to improve efficiency in Mazda's Toyo Kogyo factory regarding bottlenecks in three stamping presses. During this study he realized that setup procedures can be internal or external. As a result of this study, the bottleneck was eliminated and the efficiency was increased by 50% (Shingo, 1985).

In 1957, Shingo was invited to increase the productive capacity of a grinding equipment at Mitsubishi Heavy Industries. This problem was addressed through the installation of a second table in the grinding machine that allowed to perform setup operations individually. The increase in production was 40% (Shingo, 1996). The third moment in the development of SMED was in 1969, at Toyota Motor Company where the challenge was to reduce the setup time of a 1000 ton press that initially took four hours. After six months, the setup time was reduced to 90 minutes and the board decided to take the challenge even further setting a setup goal of three minutes. The goal was reached after three months converting internal setups into external setups (Shingo, 1996). The denomination “Single Minute” does not mean that all setups have to take only one minute, but that they would take less than 10 minutes and therefore a single digit amount of time (Dave, Yash and Nagendra, 2012).

2.2.2 Method Description

According to Shingo, SMED is a scientific approach to reduce setup times that can be applied to any equipment at any industrial facility (Shingo, 1996). It was developed and divided into four stages with the aim to separate internal and external setup operations:

- Preliminary Stage
    - Internal and external setups are not able to be distinguished, as the preliminary stage can only provide the initial time reference regarding the performed activities during setup. Times must be obtained with a stopwatch while observing the entire operation or by filming and reviewing the process (Pandya, Patel, and Pandya, 2017). It is fundamental to set the reference time while taking the type of setup in consideration. Complications can occur when a complex setup is being performed based on a quick change of format, leading to the frustration of the employees and for them to feel skill less. On the opposite, if a quick task is performed based on a longer setup time could possible lead to employees not putting their best efforts in order to complete the task as soon as possible.
- First Stage
    - Distinguishing internal and external setup, classification of the activities, sorting them into internal setups when the activities are performed while the equipment is stopped, and the external activities are performed while the equipment is functioning. If this stage is implemented right, the time reductions are between 30% to 50%, and can be accomplished without monetary investments because the improvements are related only with coordination of work (Shingo, 1985).
- Second Stage

- Exchange from internal setups to external setups. In order to perform the operations required without equipment stoppage, a reorganization of the setup stages is mandatory. It is important to understand the reason for each activity and how these activities can be performed, either before the machine stops, or after resuming its operation.

- Third Stage
  - Systematic improvement of all operations of internal and external setups. At this stage it is important to analyse every step of the operation in order to decrease its time and, possibly, to eliminate some activities in the setup operation. The single-minute setup may not have been achieved in the previous stages, meaning that continuous improvement for both internal and external setups might still be required (Shingo, 1996). With the aim to improve internal activities, three practices are mentioned by Shingo: Establishing parallel activities in order to decrease the work load; use of functional clamps to avoid waiting time while tightening; elimination of adjustments due to inaccurate placement or measuring at the beginning of the setups, (Shingo, 1985). Figure 2.4 shows the stages to implement SMED.

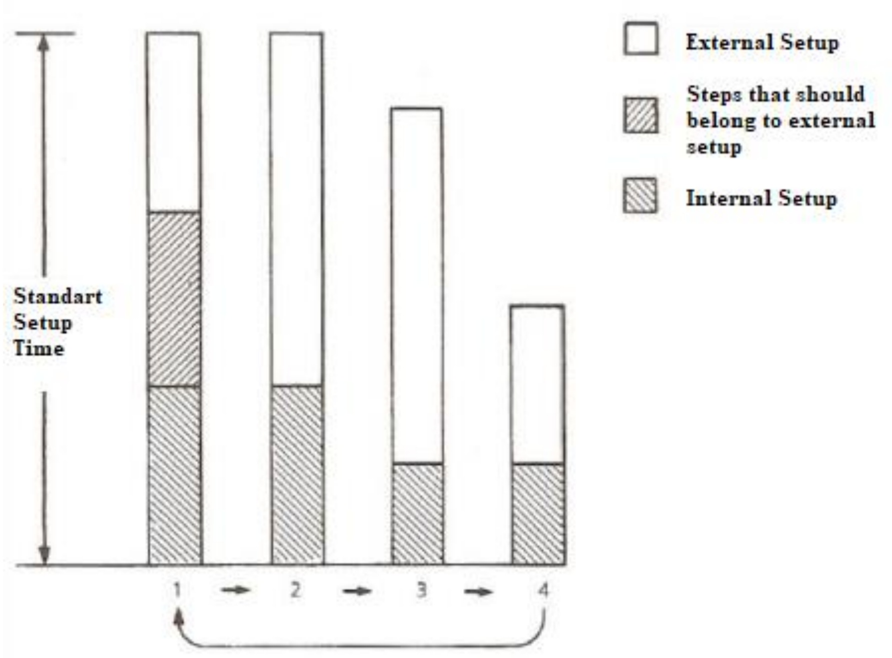

Figure 2.4 – SMED Implementation Stages

In order to achieve the best results through SMED implementation, it is necessary to analyse and improve the process in a continuous way, and new approaches can be discovered in every new analysis, always resulting in productivity increase.

2.3 TPM - Origin and Historical Background

As companies keep struggling to achieve competitive advantage and world class performance, they need to be supported by effective and efficient maintenance practices. TPM started in Japan, as an alternative to corrective maintenance. Ahuja and Khamba state that TPM is a continuous development practice that searches the improvement of the equipment's reliability, integrating production, maintenance and engineering teams (Ahuja and Khamba, 2008). According to Heizer and Render, TPM provides the increase in availability through autonomous maintenance and excellence practices of maintenance (Heizer and Render, 2013). The aim of the philosophy is the maximization if the OEE through skill increase and evolving every employee in the organization, from top management to equipment operators (Suzuki, 1994).
TPM has originated in Japan in the 1950's, as a support for the JIT production system with the general concept that, in order to assure Lean practices, the equipment's reliability and efficiency has to be guaranteed (Ahuja and Khamba, 2008). It appeared as an alternative to corrective maintenance where the intervention was performed right after the breakdown occurrence. According to Nakajima preventive maintenance was introduced in the Japanese industry after a visit to USA's industrial facilities, acknowledging the need and opportunity for its development (Nakajima, 1988). TPM was introduced in the 70's decade by Nippon Denso, a division of Toyota and this methodology was recognised by the Japan Institute of Plant Engineers (JIPE) and granted them the "PM Award" (Biasotto, Dias, and Ogliari, 2010). It is claimed that organizations where TPM is successful implemented verified a reduction of 50% in work stoppages, a 70% reduction on production losses, a 50 % to 90% cut on setup activities and up to 60% decrease of the maintenance costs (Ramesh, Sceenivasa Prasad and Srinivas, 2008).

2.3.1 Method Description

According to Nakajaima, TPM has three fundamental characteristics, related to the three understandings for the word "Total":

- Total Efficiency

  - The continuous quest for economic efficiency is based on productive and preventive maintenance (Nakajima, 1988);
- Total MP
  - Establishes a Maintenance Plan (MP) for the entire life cycle of each equipment (Nakajima, 1988);
- Total Participation
  - Autonomous maintenance performed by operators or small groups within each organizational department (Nakajima, 1988).

Suzuki, through the Japan Institute of Plant Maintenance (JIPM), defined five strategies for TPM methodology:

1) Maximize the effectiveness of productive systems, by maximizing of the OEE (Suzuki, 1994);
2) Use a methodology to prevent all kinds of loss, zero accidents, zero defects and zero breakdowns (Suzuki, 1994);
3) Evolve all organizational departments in TPM implementation (Suzuki, 1994);
4) Evolve all workers, from top management to equipment operators (Suzuki, 1994);
5) Conduct activities to improve motivation, by performing autonomous tasks in small groups (Suzuki, 1994).

TPM's role in the productivity increase of the industrial sector was recognized since JIPM introduced the concept as a path to eliminate the six main wastes, specially related to the equipment where any type of maintenance was performed (Morales Méndez and Rodriguez, 2017).

In order to achieve the improvement of OEE, for each equipment is important to identify the negative effect of each type of loss in order to prioritize strategical approaches and solve problems. Nakajima identified six sources of losses (Nakajima, 1988):

1) Loss in equipment breakdown, considered one of the main reasons towards the loss of time and efficiency in industrial facilities;
2) Losses via adjustments in the setup procedures, related to change of format;
3) Losses due to temporary stops, momentary problems in the production cycle;
4) Losses as a result of interruptions in the production speed;

5) Losses caused by defective products and the need to rework, time and money are necessary in order to repair defective products;
6) Losses attributed to start-up of equipment, in the beginning of the production cycle.

Figure 2.5 shows the relations between the six sources of loss and OEE.

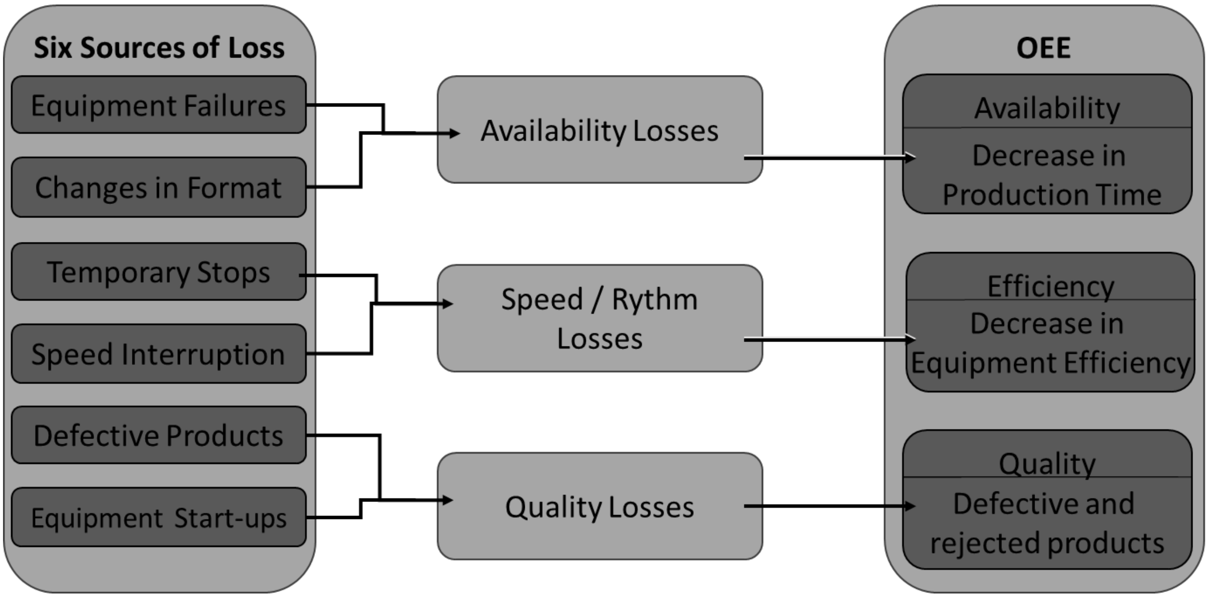

Figure 2.5 – Relationship between the 6 sources of loss and OEE

As mentioned above, one of the strategies for TPM's principles is to reach the goal of zero loss, zero defects and zero accidents, in order to improve the efficiency of the productive process, therefore increasing the overall competiveness among the organizations.

There are eight principles that sustain TPM and are referred as its pillars, represented in a house format; they require a correct sequence of introduction to guarantee the successful implementation (Nakajima, 1988). At the foundation, 5S has the purpose of reducing waste and to generate an increase in the productivity and quality through the organization of the work station. The eight pillars that support TPM´s methodology are: autonomous maintenance; focused maintenance; planned maintenance; quality maintenance; education; training; office TPM and develop management (Ahuja and Khamba, 2008). They are represented in Figure 2.6.

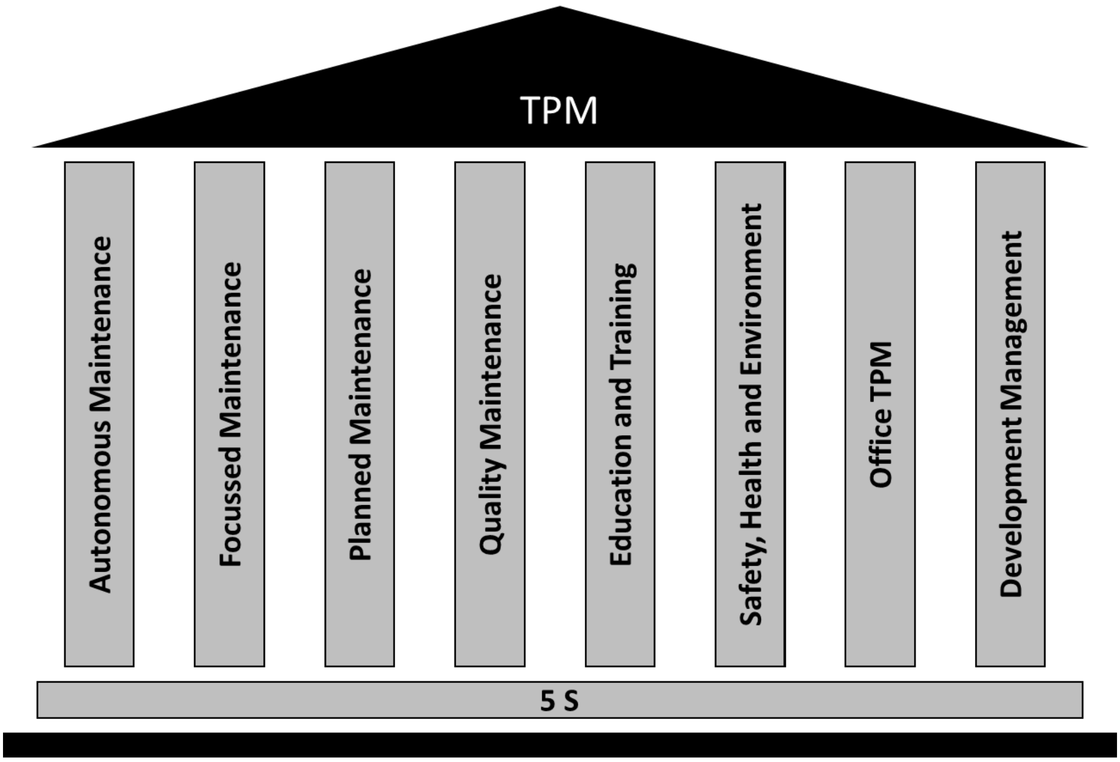

Figure 2.6 – House of TPM

TPM pursues the participation of all human resources to improve the productive availability of equipment. According to Ahuja and Khamba, TPM takes advantage of proactive and progressive maintenance methodologies, looking for the involvement of knowledge and cooperation by operators, engineers and maintenance teams to optimize the performance of the equipment, leading to the elimination of breakdowns, decrease of non-productive periods and improving product quality (Ahuja and Khamba, 2008)

3. EXPERIMENTAL WORK

3.1 Introduction

The internship took place at Fucoli – Somepal, SA. and had the duration of nine months, from October 3rd of 2017 to June 3rd of 2018. Along the nine months the focus was the optimization of processes occurred in the core manufacturing department of the organization, with special attention to the equipment BICOR 3300, considered the bottleneck of the operation. In the first weeks, several tasks were performed in different departments in order to understand the productive process of the company and later fulfil the proposed goal. This chapter will describe the work carried out such as a SMED study to improve setup times during the interchange of core boxes, a proposal to an autonomous maintenance plan with the aim of increasing the productivity among workers, standardization of some procedures to create consistency and provide faster and simpler training to new employees, plus some minor tasks.

3.2 SMED – Bicor 3300

The core manufacturing process is essential to the foundry because some of the products manufactured are hollow, therefore they need sand cores. This department sets the beginning of the productive process and triggers delays in the production due to:

- High setup times during the interchange of core boxes;
- Lack of a consistent procedure from the employees.

3.2.1 Brief Description of the Process

A mould box is composed by two half moulds and, after the sand cores are manufactured they are placed in one of the half moulds to create hollow products, as shown in Figure 3.1.

Figure 3.1 – Placement of a sand core in the foundry department

Figure 3.2 shows an example of a mould box before the top half mould (right) is rotated 180º vertically and set on top of the bottom half mould (left), where the sand cores are placed. After this step, the melted iron is poured in the top half, travels through the runners and creates one or more products.

Figure 3.2 – Placed sand cores before iron pouring

The core manufacturing department has four core manufacturing equipment to fulfil the orders placed by the headquarters and branch office:

- BICOR 3300
- 2 BICOR 3200
- BICOR 3100

The equipment are very similar to each other; the main difference is their size and the ability to produce bigger or smaller sand cores. All the equipment produce sand cores using the same cold box process that is completed in three stages:

1) filling of the core box with a mixture of sand and two types of resins;
2) fast drying of the mixture using a catalyser agent;
3) wash of the catalysing agent out with air and extraction of the core.

For this reason, the equipment has three working stations and are able to run three boxes at the same time since the stages are independent from each other, they just have to follow the mentioned order. Each station has a set of hydraulic jaws that clamp the core boxes and allows them not to move as the table rotates to complete the three stages of the productive process.

The focus of this work was BICOR 3300 (Figure 3.3), the equipment that manufactures the larger sand cores and the one that is considered the bottleneck of the operation. For numerous times, mould plates production was delayed in foundry due to the fact that cores needed were not manufactured yet. The setup times to interchange core boxes, as the production required, were high; additionally, the size and weight of some of the cores produced also made the extraction and handling a slow process.

Figure 3.3 – BICOR 3300

In this particular application, the setup times are only related to changeover between core boxes; there are no other types of format change. The main challenge was that over 200 core boxes could fit in the BICOR 3300 only, and they were different in terms of sizes, construction method, extraction method, fastening and several other dissimilarities. For this reason, the procedure was not consistent and the approach was the attempt to provide all the resources needed in order to perform the changeover.

3.2.2 Diagnosis and set of Benchmark Times

The first order of business was to measure the setup times while performing random changeovers. The method stood by the identification of each operation performed by the employees and keep track of the time spent until the operations were completed. The times were measured with a stopwatch based on 15 successful changeovers and are shown in Table 3.1.

Table 3.1 – Times Measured

Times Measured During Setup	
Lowest	13:56
Average	39:14
Highest	46:37

Based on the times measured it was pretty clear that setups shown discrepancies due to the different characteristics of the several boxes used in this equipment. Transport and fixation was easier in the smaller units, therefore taking less time. The scavenge for tools and parts was also noticed as a time consuming operation, due to the lack of availability of the right tools and organization of the work space. To summarize, the lack of procedures and the non standardization of processes between employees was further delaying the setup operations.

3.2.3 Attempt of SMED Implementation

After the diagnosis was performed and times were set, it was attempted to perform some of the steps of the Single Minute Exchange of Die (SMED) methodology. The preliminary stage was half completed with the times measured so, the next step was identifying the tasks performed by the employees. In order to complete a core box changeover, the employees would:

- Register the production and fill in a core box sheet in order to report possible issues occurred during production;
- Remove the fixation studs. If the core box was attached vertically, eight studs needed to be removed by hand, if it was attached horizontally and only four studs were used and removed with the help of an air-driven tool. This parameter depended on the design of the core box;
- General clean-up of the core box to eliminate leftover residues of sand using pressurized air;
- Set up the crane to take away the box, although sometimes they were removed by hand;
- Displacement of the box to the sequencer that flows out of the production site;
- Clean up of the station where the box was previously placed to remove leftovers of sand;

- Pick up and placement of the next box set to production from the sequencer that flows into the production site using the crane. Manually execution of this step also happened;
- Adjustments to place the box in the centre of both hydraulic jaws;
- Re-attach the four or eight fixation studs;
- Insert the specific parameters for the next production batch.

In the first stage, tasks were distinguished and classified as internal (I) and external (E):

- internal setups when the activities are performed while the equipment is stopped;
- external setups when activities are performed while the equipment is functioning, as shown in Table 3.2.

Table 3.2 – Distinction between internal and external tasks

	Tasks	I/E
1	Production registry	E
2	Removal of the fixation studs	I
3	General clean-up of the core box	E
4	Set up the crane to take away the box	I
5	Displacement of the box to the sequencer	I
6	Clean up of the station	I
7	Pick up and placement of the next box	I
8	Adjustments	I
9	Re-attachment of the fixation studs	I
10	Insert parameters on the equipment	E

As the equipment possesses three working stations, the spare time between the last step of the procedure and the need to extract the core from the oncoming station was reduced. Between extractions the equipment took approximately three minutes and the possibility to perform the external tasks in that amount of time was out of the equation. It would lead the employees to run around the working station, switching from accomplishing the external tasks and being in position to execute the extraction without affecting the availability of the equipment. The proposal to place a second employee to help in the setup operations was denied.

Therefore, the typical SMED implementation was not able to be completed, but the improvement of the setup processes was a goal that could still be achieved. The author started to focus on the more time consuming tasks and noticed that the removal, re-attachment of the fixation studs and the adjustments necessary to complete the placement in the centre of the hydraulic jaws had space for improvement.

As mentioned above, when the boxes were attached vertically the studs were placed with a manual wrench. The hydraulic jaws needed to be adjusted according to the length of the core box, this adjustment was performed through an end course sensor. It was a trial and error procedure and, naturally, took its time to complete. A rod was connected to one of the hydraulic jaws so, the movement occured simultaneously. A cylinder was attached to the same rod and, as soon as the cylinder reaches the sensor, the extension of the hydraulic jaws ends. This extension could be adjusted by moving the cylinder back and forward through the rod.

It was also noticed that the flow of the setup processes was often interrupted due to the organization of the work station. The stacking of unnecessary core boxes around the work area led to constraints in the placement and the pick up of soon to be produced units plus the expedition of units that finished production.

With the expectation of solving some of the noticed issues an action plan was created to improve the flow of the general setup process by organizing the working station and making available all the resources needed in order not to waste time on unnecessary activities. The actions are described below.

1) Elimination of contamination sources to improve the time spent cleaning the core boxes before removing them from production. This measure was considered after watching employees spending a large amount of time cleaning the excess of and from cavities like the ones shown in Figure 3.4.

Figure 3.4 – Cavities that should be covered

This measure could be accomplished by covering the top of the cavities with leftover supplies existing in the carpentry, providing an inexpensive solution and prevent the time spent cleaning. At this point, it is important to say that it was imposed by the company that boxes should be cleaned before exiting production;

2) Modifying the height and replacing the broken plastic rollers of the sequence platform to improve movements into or out the workstation.
The logistics train transports the core boxes from the carpentry to the production site in metal conveyors that were placed near the sequence platform created to promote the flow in and out of the production site, as Figure 3.5 shows.

Figure 3.5 – Conveyors used to transport core boxes

This sequence platform was created in an early intervention performed by the consulting team responsible for Lean implementation at Fucoli, as shown in Figure 3.6.

Figure 3.6 – Existing sequence platform

The design had flaws, as the height of the platform would not match with the height of the conveyors leading to additional efforts when handling the core boxes. The plastic rollers also needed replacement.

3) Development of a graduate device to accurately regulate the necessary length when placing the boxes in the centre of the hydraulic jaws.

   As mentioned above, the adjustments were one of the more time consuming tasks due to the current trial and error process that was performed. The proposed solution was the development of a graduated rod that allowed to register the position of the cylinder in relation to the rod for each core box, providing the exact length to properly place the boxes. It would be a time consuming process to register all the necessary lengths; however, in a long term perspective, the adjustments would be significantly faster. The part was designed with the aid of drawing software and it is shown in Figure 3.7.

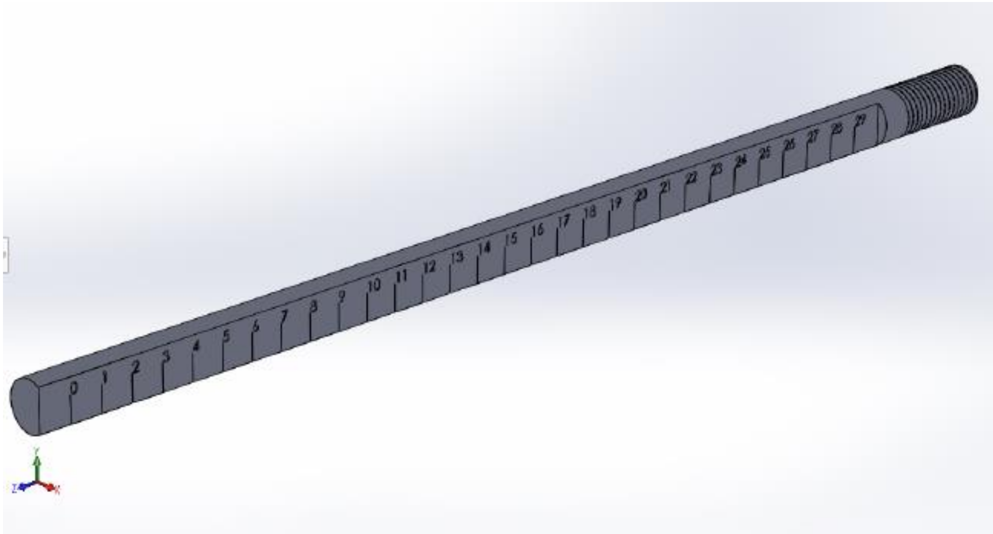

Figure 3.7 – 3D representation of the graduated tool

4) Establishment of three standardized lengths for the core boxes in order to prevent such adjustments.

   This action is related to the previous one, the development of three standardized lengths for the core boxes based on the original dimensions. It would allow the definition of three standard adjustment settings, eliminating the need for adjustments, as each core box dimension would have a correspondent setting. However, it would take significant resources to complete this action in terms of labour and materials.

5) Buy and make available a 19 mm deep socket to eliminate the manual tightening of the fixation studs.

   As mentioned above, core boxes could have horizontally or vertically fixations that used four and eight studs respectively. When the boxes were vertically fixed the studs were removed by hand and it was noticed that a great amount of time was being spent performing that task. For that reason and the fact that an air-driven tool was already available at the work station, a 19 mm deep socket was bought providing the ability to fasten all the studs faster.

6) Increasing the length of the air lines in order to easily reach the inside of the equipment when tightening the studs.

   This measure is related to the previous one; the backside of the vertically fixed core boxes was hard to reach on the existing air hose, therefore the request to increase its length was done.

7) Development of a magnetic clamping system to avoid the fixation through studs and reducing times related to the fastening of the boxes.

As the equipment was equipped with an electromagnet system built-in the hydraulic jaws, it arised the opportunity to develop a magnetic clamping system to completely eradicate the task of fastening studs (Figure 3.8). Modifications had to be made and six metal stripes were attached to both sides of the core boxes at the same height of the electromagnets.

Figure 3.8 – Electromagnetic System

To perform this action, the system was tested by the maintenance team to assure its correct functioning, since it had not been used from the day the equipment was acquired.

8) Acquisition of a box to hold the chain of the crane, as it would get in the way during the movements on the sequencer.
   The rolling crane was poorly placed in between the production sequence platform, as can be seen in Figure 3.6. The chain was exposed as a result of a previous accident and it would cause trouble when handling the core boxes in and out of the production site. The device to hold the chain was fairly cheap, and it might seem as a small detail but, actually, made a lot of difference.
9) Reorganization of the workstation.
   It has been early noticed that all around the setup processes, inconsistency and lack of procedures were predominant, thereby triggering the delays previously mentioned.

Organization of the work space is the main reason for the encountered issues, as for many occasions employees would spend significant amount of time in the search of tools or other necessary resources. As can be seen in Figure 3.9, this set of studs was out of place and contained many broken units that were creating misguidance when attempting to find a functional unit.

Figure 3.9 – Misplaced fixation studs

The workstation was very often dirty and unorganized, as shown in Figure 3.10, leading to general low productivity.

Figure 3.10 – State of the work station

The productive process for manufacturig cores implies the need to perform rework tasks after its extraction. Often, feeding channels need to be parted with main piece as they are not used, edges need to be filed and painting of the cores is a commun process aswell. The amout of tasks performed in order to complete the entire process led to clusters of cabinets with work in progress and finished products, as shown in Figure 3.11.

Figure 3.11 – Cluster of cabinets often noticed

Specific accessories were often use as jigs to support the weight of the cores in the process of extraction. As shown in Figures 3.12 and 3.13, they were spread through the floors of the working space without labels.

Figure 3.12 – Unorganized accessories

Although the two employees that share this work station possess several years of experience with this equipment and accessories; mistakes on the selection of the correct accessories were common and instigated more time losses.

Figure 3.13 – Unorganized accessories

The thought of acquiring a work bench, to organize and label the accessories, tools and other resources were proposed.

This summarizes all the actions that were initially planned in order to improve the general concept and persecute the optimization of setup processes regarding the core boxes interchange occurred in the core manufacturing department of this company. The SMED approach took a different course and turned into a plan of actions that was developed to improve the benchmark times by changing the environment around it. Further conclusions on the results are discussed in the fourth chapter of this work.

3.3 Autonomous Maintenance Plan

The process of core manufacturing is rough on equipment; the raw materials used are silica sand mixed with two bonding agents and then pressurized into the core boxes. As the process was not 100% sealed and leakage of the mixture happened, the amount of build-up residues led to an increased wear on some of the components located inside of the equipment. For that reason and the intrinsic goal to achieve higher levels of productivity, an autonomous maintenance plan was initiated. Autonomous maintenance is based on the principal that if operators apply basic maintenance on their working equipment, they will discharge maintenance technicians who can concentrate on value added activities and technical repairs. According to Singh Rajput and Jayaswal there are seven stages to the implementation of autonomous maintenance (Singh Rajput and Jayaswal, 2012):

1) Initial cleaning - Completely eliminate the built-in residues of the equipment, as well as the detection of problems and their repairs;
2) Measures to reduce sources of contamination and hard to reach locations - Carry out improvements relative to the sources of dirt, prevention of spills and locations of difficult cleaning and lubrication, to diminish the time spent in these procedures;
3) Elaboration of cleaning and lubrication standards - Carry out cleaning activities in the shortest amount of time possible;
4) General inspection - Detection and restoration of equipment failures through the application of general inspection techniques;
5) Autonomous inspection - Elaboration and execution of an inspection sheet;
6) Organization and order - Carry out the standardization of the control items for the workplace and total systematization of their maintenance. Cleaning inspections and lubrication standards, material flow in the workplace, tools and devices control standards;
7) Consolidation - Develop guidelines, goals and regularly record improvement activities.

3. EXPRIMENTAL WORK

In the core manufacturing department, a large number of micro stops was being registered on a daily basis. Events that took from one to five minutes to solve, mostly related to equipment stoppage due to sensor failures. The goal was to increase the skill level of the employees regarding the understanding of the process and to increase the abilities to perform a quick diagnosis in order to solve the issues. This action would allow the autonomy of employees regarding their equipment and reduce the load on the maintenance team support to this department, increasing their availability for other occurrences. The autonomous maintenance plan was set in motion and the first stage included the identification of the critical components and the initial cleaning, as proposed by Singh Rajput and Jayaswal (2012). The components were identified and divided in four categories, as described below:

- Electric:
  - Switchboard;
  - Electric motor;
  - Sensors: table rotation, blowing unit and gasification unit.
- Hydraulic:
  - Hydraulic group - hydraulic pump;
  - Hydraulic lines - for the hydraulic jaws, main door and table rotation;
  - Hydraulic cylinders - two for the extraction table, six for the three working stations and one for table rotation.
- Mechanic:
  - Sand blasting unit;
  - Aluminium base of the sand blasting unit;
  - Table rotation bearings.
- Pneumatic:
  - Pneumatic cylinder for the silo drawer;
  - Pneumatic cylinder for the main door;
  - Blowing head unit 502.

The development of inspection and maintenance routines remained responsibility of the maintenance team after the initial clean-up of the equipment. It was important to identify the critical components and understand their function. It was suggested the creation of a critical component sheet, with information relating the component's functions and the possible causes for failure, with the purpose of improving the diagnosis abilities. It is stated that in this type of approach the equipment should be recovered to its initial state, although the technical support from the manufacturer is non-existent and only a general clean-up was performed. In the following figures it might not be noticeable the amount of contamination that was removed from the inside of the equipment, specially below the rotary table. The work was carried from the top of the equipment down, where is located the mixer that combines the silica sand with the two resins. Figure 3.14 shows the mixer with both covers attached and the beginning of the disassembly by removing the first cover.

Figure 3.14 – Mixer ready to be disassembled

After analysing with half of its cover off, we can realise that the sand travels from the back of the propeller through a worm screw and, then is joined with the black and white resins that come out of the first two channels placed on the top of the assembly. This mixture is certainly rough to clean after its dry. Accessories like picks and sharp razors are helpful in this step of the process (Figure 3.15).

Figure 3.15 – Cleaning of the propeller

A cleaning agent is also applied in order to help in the process of removing the resins that were gathered during several months. As we can see in Figure 3.16, the result was not perfect due to the hardness of the resins and there was no other solution besides the disassembly of the entire unit what would compromise the productive process due to the required time to perform the maintenance operation.

Figure 3.16 – Final result

The covers were also serviced with the help of the core manufacturing department employees. The state was the same, substantial build ups of resin and sand. It is important to say that in this particular case, it was not hurting the performance of the equipment; however, they were clean in depth to set standards for the daily task of cleaning, as shown in Figure 3.17.

Figure 3.17 – Covers of the mixer before and after intervention

The next step was to service the bottom side of the equipment, where the core boxes go through the three production stages. It is in this location that the principal and faultiest sensors are placed. This was cleaned using a shovel for the most demanding areas and finished with pressurized air. Figure 3.18 shows the sand blasting unit where the boxes are filled.

Figure 3.18 – Sand blasting unit

The sand blasting unit was considered the main source of contamination; its aluminium base seals against a piece of rubber strip attached to the top of the core boxes; however, the pressurized sand deteriorates the aluminium and leakages are frequent. The gassing unit has a similar system to prevent leaks, as is shown in Figure 3.19. Although the chemical does not hurt the equipment it is harmful to human health.

Figure 3.19 – Gassing unit

Figure 3.20 shows the general layout of the equipment, with the three working stations, filling the core boxes, drying the core with the use of the catalyser and, finally, the extraction station.

Figure 3.20 – Inside layout of the equipment

Although the state of the equipment was significantly improved, the traces of continuous years without proper cleaning were still present. Figure 3.21 shows the backside of the equipment, below the sand blasting unit where it can be seen severe resin build up. The equipment suffered an intervention for three consecutive days when the production demand was low and, besides the efforts put into this task, the older residues were difficult to eliminate.

Figure 3.21 – Remaining residues after cleaning

The undercarriage of the equipment was the area where more contamination was removed from. It holds room for the hydraulic lines of the equipment and they were difficult to reach in its previous state. There is no photographic registry of this location of the equipment. The general clean-up of the equipment allowed setting of standards for future references and provided a small decrease of sensor related failures in the next days of work. The set goal was to, at least, to maintain the equipment in this state after the daily clean up routine. The autonomous maintenance implementation was then carried on by the maintenance team and the results obtained until the end of the internship are discussed in the fourth chapter.

3.4 Standardization of Procedures

As a result of the work performed in the SMED attempt plus the autonomous maintenance implementation, it came the opportunity to make standard the interchange of the core boxes and the daily cleaning routine procedures. If we could achieve consistency when performing this procedure, an increase in productivity should be noticed. As the employee's skills to diagnose and solve small issues increases, the need to call the maintenance team is reduced. Regarding the change of setup procedures, it would benefit the time spent in this type of operations and provide a flawless sequence to prevent non added value activities performed by employees.

This process is also important to deliver an easier and faster learning experience to new employees plus increasing multifunctionality among current operators from other working stations. The document created was objective and easy to understand, a subject that never performed that type of work should be able to successfully complete the process by only following the document's direction's.

Besides the daily cleaning routine and the changeover process, in an early stage of the internship, other documents were created regarding the process to refurbish the devices used to pour the melted iron into the moulds. It was a daily procedure where the refractory surface of the spoon and tundish were replaced. The other document created regards the correct operation sequence for the automatic inoculator used in the foundry process.

3.5 Other improvements performed

3.5.1 Elimination of the covers from the core boxes

As mentioned above in this paper, the cores are manufactured using the cold box method, where a mixture of sand and resin is pressurized into the core boxes and then hardened with a catalysing agent. Among the four core manufacturing equipment, hundreds of cores were produced on a daily basis. Therefore, the concern to accurately control the consumption of sand was carried out since the first weeks of the internship. One of the daily tasks was random weighing the cores that were produced in order to understand the amount of sand that was used for the final product in comparison to the amount of sand that was wasted. The weights were registered and these daily tasks allowed to determine the efficiency of the core boxes. Figure 3.22 shows the products of the core box number 259; it was noticed that, in this case, the weight of the non used sand was eight times higher than the actual product.

Figure 3.22 – Products of core box number 259

Most of the core boxes had covers that were placed on the top and would help guide the sand to its interior allowing the complete fill. The sand placed in the opening channels was not used, therefore, the measures were taken in order to eliminate the cover of the least efficient core boxes. This project was performed with the design department of the company. Several difficulties were encountered, namely the incomplete filling of the core boxes, causing damaged and unable to use products, as shown in Figure 3.23.

Figure 3.23 – Faulty filling of the core box

Besides the difficulties encountered, the design team was able to improve the entry channels and successfully apply this measure in some of the core boxes, increasing the efficiency of those units and eliminating excess waste of sand.

3.5.2 Creation of a wharf for the logistics train

The Coimbra production unit has an indoor area of 28.700 square meters, and the lot is approximately 110.000 square meters, meaning that the transport of the mould plates and core boxes from the carpentry to the foundry and core making departments was carried out by a logistics train. A logistics train is used to transport necessary supplies to the different production areas. At this company, the logistics train completes its circuit every hour and its stops are spread out through the entire facility. The circuit starts at the carpentry and ends in the main building where the foundry and core making processes occur.

Numerous difficulties were reported due to the fact that the logistics train was miss positioned and caused hold ups in the flow of the productive process. In order to solve this problem two wharfs were created in the start and end of the logistics train circuit as shown in Figure 3.24. The green and red stripes represent the departure and arrival locations, respectively.

Figure 3.24 – Wharf created in the carpentry

4. DISCUSSION

The present chapter was created with the purpose of disclosing the results achieved after the attempt to implement the methodologies mentioned in the previous chapter of this work. Several actions were attempted in order to improve the overall productivity of the sector, from setup times, maximizing the efficiency of the process through the design improvements on the core boxes, increase of the employee's skills and creation of consistent procedures. A brief analysis of the actions performed as well as an update on the state of the process is described below.

The typical SMED implementation showed its limitations due to the fact that employees did not have enough time to perform external activities and working the equipment without slowing down the productive process. As mentioned before the gap between extractions was not long enough, in fact only two to three minutes were available between the need for the employee to be back on its working position. For that reason an action plan was developed to improve the environment where the process was being performed, as demonstrated on Figure 4.1.

Fucoli - Somepal ■ SEDE – Coimbra ☐ FILIAL – Pampilhosa	PLANO DE ACÇÕES (Macharia) ☐ Qualidade ☐ Ambiente ☐ Higiene e Segurança	Data de Emissão: Revisão:	Elaborado por:	Aprovado por:

	ACTIONS	MEANS	Execution Control					Responsible Entity	Date	
			20	40	60	80	100%		Started	Closed
1.	Elimination of contamination sources to improve the time spent cleaning the core boxes before removing them from production.	Internal								
2.	Modify the height and replace the broken plastic rollers of the sequence platform to improve movements into or out the of work station.	Internal								
3.	Development of a graduate device to regulate the length and allowing less adjustments.	Internal								
4.	Creation of three standardized lengths for the core boxes in order to prevent such adjustments.	Internal								
5.	Buy and make available a 19 mm deep socket to eliminate the manual tightening of the fixation studs.	Internal							24/03/18	17/04/18
6.	Increase the length of the air lines in order to be able to easily reach the inside of the equipment when tightening the studs.	Internal								
7.	Development of a magnetic clamping system to avoid the fixation through studs and reduce times related to the fastening of the boxes.	Internal								
8.	Acquisition of a box to hold the chain of the crane as it would get in the way during the movements on the sequencer.	Internal							24/03/18	15/05/18
9.	Reorganization of the work station.	Internal								

Figure 4.1 – Action Plan

As demonstrated; nine actions were developed throughout the implementation of this approach, the charter shows the actual state of the developments until the end of the internship. As we can observe, only two of the nine actions were finished, a brief commentary is made below following the order from the finished actions to the ones that did not suffer any type of development.

- Actions 5 and 8: A 19 mm deep socket to allow fastening of the fixation studs with the aid of an air-driven tool was bought and made available for the employees. This led to the completion of a process that used to take from five to eight minutes in less than four minutes, for every attempt that was timed after this action was finished. This action was reasonably simple to achieve, however it took almost four weeks to complete. In the same day, the tool was made available for the employees and the box to hold the chain of the rolling crane was installed, allowing a better manipulation of the core boxes in the sequence platform. Both actions helped the process, nevertheless there was the need to achieve more.
- Action 7: Developing the magnetic clamping system was the most efficient measure that was implemented, however only two core boxes are currently operating this system. This action allowed the interchange of the two modified units under twenty minutes, which is almost twice as fast as the average benchmarked in the previous chapter. Several difficulties were encountered, as the magnetic system had never been used before, for that reason it took the maintenance team a while to assure the equipment was entirely able to function. After the system was fully operating, the boxes were modified and the tests started. Both halves of the core boxes were magnetically clamped to the hydraulic jaws and as extraction started the jaws would open, carrying each half of the box with them. A jig was used to ensure the core remained in position, as the assembly shifted and the table extended from the inside of the equipment to allow its extraction. As mentioned, the setup times improved quite a bit on those two core boxes, however the products were being damaged by the abruptness movement provided by the equipment when the half's of the core boxes started to split. One of the halves would drag the core placed in the centre, causing it to break. Intense testing continued after several modifications to the structure of the boxes. In the previously tested versions the bottom of the structure was built using medium density fibreboard (MDF) that provided low structural integrity. The bottom was rebuilt using resin and this action provided extraction of the products with maximum quality. This action is claimed at 80% due to the fact that a lot of effort was imputed from all parties involved to make this system work, however it needs to be expanded to as many units as possible.

The next commentary regards somewhat developed activities where time was spent trying to come up with solutions for the stated issues but never managed to be carried out entirely.

- Action 9: The action to reorganize the work station was partially completed, partially meaning that at some point the work space was indeed organized, clean and allowing a work flow as it never did before. This step took a lot of effort in order to change the employees mentality to maintain the condition of the work space, as they would easily return to old habits leading to the obvious degradation. In order to eliminate the demonstrated clusters that were happening in this area, the operator of the logistics train had the responsibility to check the state of the production in order to take away all the unnecessary units and maintain the ones that were actually in use or soon to be in used. This took some time to achieve but in the end was working flawlessly.

- Actions 3: Development of a device to reduce the amount of adjustments made when interchanging core boxes. Some progress was achieved since it was an idea as it translated to a three dimensional drawing of the tool. A solution to manufacture the tool with the aid of a lathe and a mill was provided at zero costs. As we can see in the figure this measure remained at 40% completion because it was not further developed so it was not implemented.
- Action 4: Development of three standardized lengths for the core boxes and as the previous measure, some time was spent developing this idea. Three consecutive days were necessary to catalogue the dimensions of all the boxes compatible with BICOR 3300. After all the dimensions were gathered in a Excel sheet they were separated into three categories depending on the initial length of the core box. As mentioned in the previous chapter this action would be expensive for the reason that a considerable amount of lumber would be necessary. Along with the costs of the materials it would take work from one of the carpenters, and at that point all the human resources had no time to spend on such tasks. Therefore this action was not further developed as well, as it would not bring the necessary yield to justify the time that needed to be dedicated.

The final section regards the actions that were not developed whatsoever after the proposal of the action plan to achieve better setup times.

- Action 1: The task of covering the unnecessary openings of the core boxes to eliminate contamination was never further developed. It was considered an occasional event, caused by the sand leaks from the sand blasting unit. Although this happened occasionally, it was a fact that serious time was spent cleaning the orifices after a complete production cycle when the mixture of sand was hardened. Leftovers of lumber should have been used to fix this issue, as the cost was mostly inexistent.
- Action 2: The improvements were never achieved on the core boxes sequencer platform. In order to complete this measure, modifications were needed and at the time there were no human resources available from the maintenance team to cut the actual

platform, modify it and finally weld in in place. In addition, the plastic rollers needed replacement which had its cost associated. This measure was classified not urgent, besides the author's opinion that this small change would improve the manipulation of the boxes in and out of the production site.

- Action 6: In order to provide the best conditions for the use of the air-driven tools, the length of the airlines could be extended. The needed materials existed in house and it was a task that could quickly be completed at the end of the production shifts. This measure was never followed through because the existing line was working and was considered minor improvement, besides the fact that employees struggled to reach the fixation studs located in the back of the core boxes daily.

In general the setup times were slightly improved, accounting the difficulties that were encountered along the process. Besides the reasons for the non developed measures, changing the habits of the employees was the most difficult to achieve task. The considerable amount of years performing this process led to the creation of routines that were not ideal to achieve maximum productivity.

From time to time the possibility of adding a second employee to help in this particular work station was debated but the main conclusion was that it was better to relocate man power from other stations when necessary, full time assistance was not worthy. Nevertheless room for improvement was still available and every change on the organizational culture is a step forward to reach full optimization of the processes.

The next observation regards the autonomous maintenance plan and the developments that were achieved during the implementation as well as the state of the process until the end of the internship.

As mentioned in the previous chapter, the first order of business was to identify the critical components of the equipment and perform a meticulous clean to the equipment in general. After this actions were performed, the amount of micro stops decreased slightly as the employees became more aware of the causes of the mentioned micro stops, mainly caused by faulty sensors. Due to the creation of the standardized cleaning process, the general state of the equipment improved and most of the established standards when performing the initial clean up were followed through.

In the previous chapter it was mentioned the suggestion to create a critical component sheet that would contain brief information of the most faulty components and possible reasons for the failure of each component, although this action was never further developed. Employees were briefly instructed to solve the problems that occurred often and it served as a temporary solution for this action.

Three maintenance routines were developed according to the frequency to perform such actions:

- Daily routine: the clean-up of the equipment would be performed according to the standardized procedure at the end of the daily production cycle;
- Weekly routine: check-up the level of fluids in the hydraulic group necessary for the correct operation of the equipment;
- Monthly routine: check less priority components, like the wear of the mixer blades or on the aluminium base for the sand blasting unit and replace them if necessary.

A document with barcodes associated to the most important components of the equipment was created as demonstrated in the Figure 4.2. The codes were misplaced on the sheet to improve the reading process with the barcode scanner device and prevent misreading by the employees.

This system was still in progress but the goal for its implementation was identifying the components upon reading the barcode with the scanner device, and get access to the maintenance management software where consumables for each component could be checked.

PORTA
BICOR 3300
MISTURADORA
MESA
DOSEADOR
GRUPO HIDRÁULICO
QUADRO ELÉTRICO
GASEADOR
MANDÍBULAS

Figure 4.2 – Barcodes generated for each component

This should be a helpful improvement measure although only maintenance engineers and few selected personnel had access to the management software.

Unfortunately by the time the internship ended the developed routines were still not being performed by the equipment's operators besides the daily cleaning action. The next step for the maintenance team was creating a visual chart to control the execution of the mentioned actions by the employees. The chart also contained the frequency of the planned tasks as well as the necessary tools to conduct them.

To summarize, the autonomous maintenance implementation was not completed besides the small improvements on the performance of the equipment. On a positive note, the awareness of the employees regarding the state of the equipment increased, plus the ability to diagnose and solve small issues provided less dependence on the maintenance staff. The support from the maintenance department regarding this matter was massive.

Overall the core making department had low efficiency even after the successful implemented actions. The OEE values were low due to the age of the equipment plus the efficiency of the productive process itself. It is stated that a world class performance OEE should be 85% or higher, the numbers on the core manufacturing department could fluctuate from 8.86% that was the lowest number registered to 71.04% that was the highest value registered. There were several days that OEE was not calculated, mainly because of changes made in the method of calculation. Figure 4.3 and 4.4 represent the OEE fluctuation in BICOR 3300 during the months of April and May of 2018, respectively.

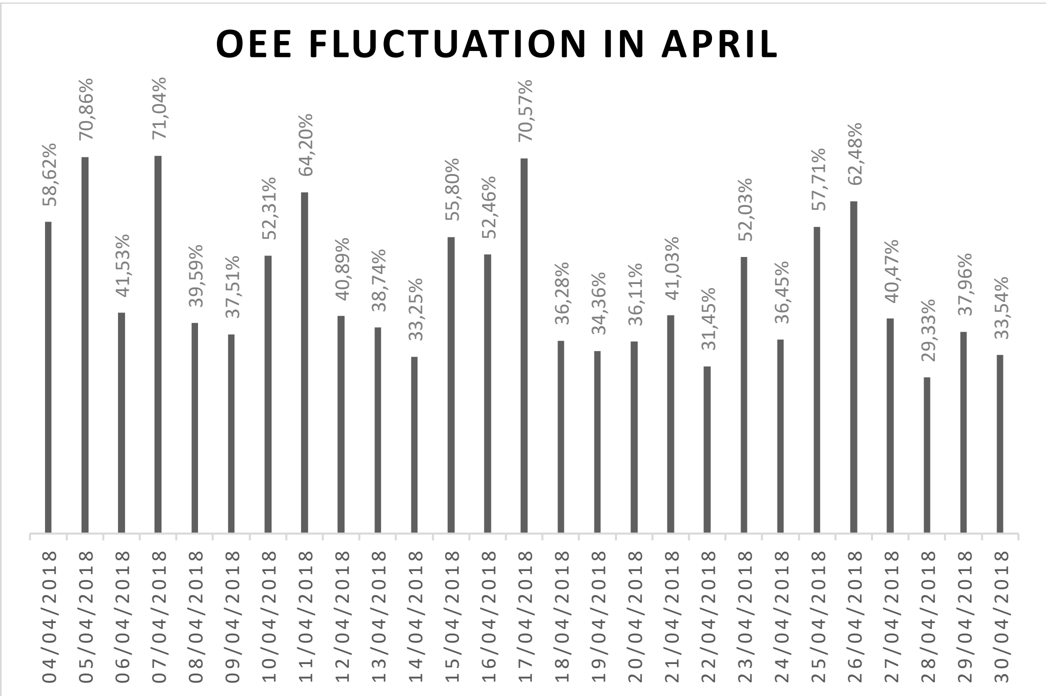

Figure 4.3 – Chart of OEE fluctuation during April 2018

4.DISCUSSION

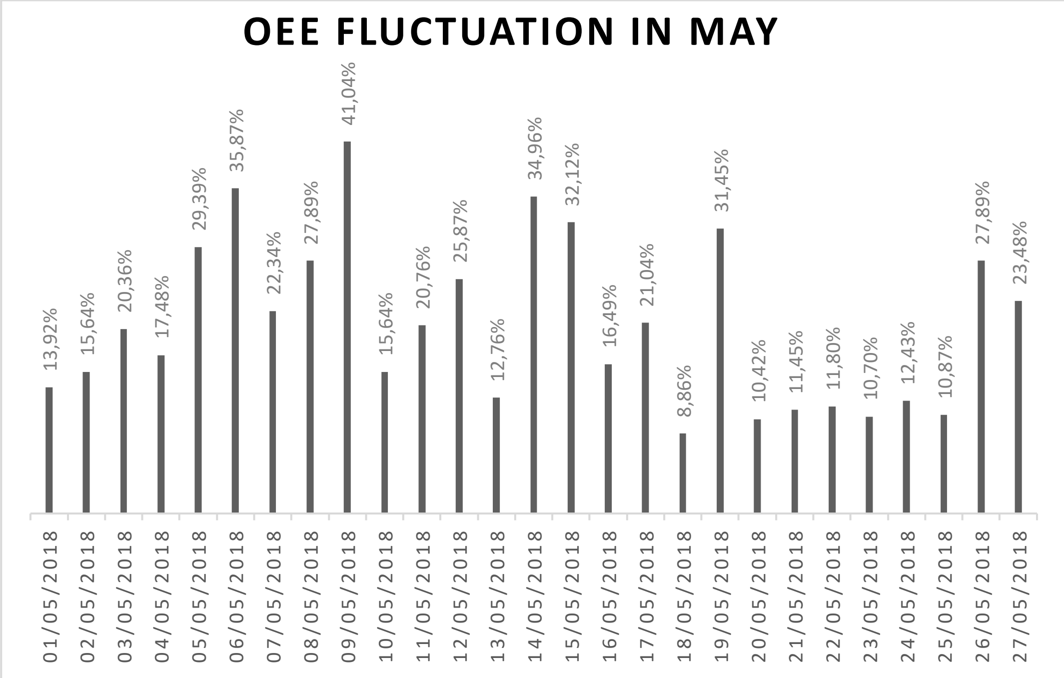

Figure 4.4 – Chart of OEE fluctuation during May 2018

A large number of the products manufactured presented high numbers of scrap units every day. Factors like the mixture ratio of bonding resins with sand could compromise the quality of the final products, wasting a morning of work. Several core boxes needed repairs that were registered and would come back to the next production cycle in the exactly same state, even if it was days after. The key to succeed in this type of actions is organization and control the execution of the scheduled tasks from the floor managers in each department.

The final though is that much more could be accomplished along the nine months integrated in this company. Organizational culture was predominantly inexistent besides the long term Lean philosophy implementation, that started in 2011. Many times the foundry process would be prioritized over all the secondary processes and compromised further development of actions that were related to the primary goal of an entire improvement process. The attempt to implement several measures at the same time led to the completion of none, instead small progress was made over large amounts of time. The communication between departments was ineffective as well, providing delays in the flow of processes.

The role of leadership, expertise and power of decision are key factors to achieve successful implementation in any kind of improvement methodology. It must assure long term orientation and availability to set up and maintain Lean Manufacturing practices. Lack of expertise is the main influencer when dealing with Lean Manufacturing management principles. In typical SME’s the power of decision is centred in the leader, therefore their involvement and support is extremely important.

5. CONCLUSIONS AND PROPOSALS FOR FUTURE WORK

The present chapter regards the conclusions of the work performed in order to improve productive processes in the core manufacturing department of this company, as well as future work perspectives in order to complete the pre-established goal.

5.1 Concluding Remarks

The goal that was initially set for this internship was not completely fulfilled, although this experience was beneficial for the author's integration in the manufacturing industry. It was a very educational experience from the practical point of view since it allowed to work with industrial equipment and to participate actively in the development and implementation of procedures to improve the productive processes. At the same time provided a general idea of how an industrial facility operates regarding production management, management of employees and coordination for the entire operation.

One of the goals of this work was to disclose different approaches to implement Lean Manufacturing in organizations as well as the benefits that Lean can provide regarding improvements in the productive processes. It is also the methodology to follow in order to achieve and sustain competitive advantage in the current state of the manufacturing industry.

This work also intended to enhance the difficulties that are faced by SME's while correctly implementing Lean Manufacturing. Besides the lack of information high percentage of implementations fail, as the characteristics of a SME are different than a large corporations. Lack of expertise, short term strategies and lack of resources are the main reasons for failed approaches.

In the core manufacturing department the work performed throughout the year provided slight improvements regarding the setup times to interchange core boxes as well as an increase in the organization of the work space and an increase in the awareness of employees regarding the maintenance of their equipment. Nevertheless the work could be further developed, several difficulties that are mentioned in the previous chapter were encountered and worked as a barrier to complete the initially established goals.

It is believed that such implementation could have a different outcome if each improvement measure was carried through from the beginning in until the end. For several times, multiple projects were being worked on simultaneously, however none suffered complete closure.

5.2 Future Perspectives

In order to fulfil the implementation of the performed work a number of aspects have warehouses to be taken in consideration. The autonomous maintenance routines need to be practiced by the employees and a continuous improvement cycle has to be set in motion to detect possible failures in the established procedures, as well as the addition of steps to the routines. As soon as the approach is suitable for BICOR 3300, the next goal is to expand the autonomous maintenance plan to the other three core manufacturing equipment in this department.

Regarding the improvement of setup times, it is necessary to modify the greatest amount of core boxes as possible to work with the magnetic clamping system developed in the same equipment.

The layout of core manufacturing warehouse needs to be improved in order to provide the best flow of cabinets as possible. At is current state employees needed to move two or three cabinets in order to accomplish a First In First Out (FIFO) consumption of the cores for the Make To Stock (MTS) products.

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