FLAVIO CASAZZA

IMPROVING CAPACITY UTILIZATION IN AN AUTO PARTS SUPPLIER THROUGH WCM METHODS AND TOOLS

Graduation work presented at Escola Politècnica da Universidade de São Paulo for the accomplishment of the "Diploma de Engenheiro de Produçao"

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“Everybody is a genius. But if you judge a fish by its ability to climb a tree it will live its whole life believing that it is stupid”

Albert Einstein

“Be who you are and say what you feel, because those who mind don’t matter and who matter don’t mind”

Dr. Seuss

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ABSTRACT

This dissertation explores the benefits of World Class Manufacturing (WCM) in a medium size automotive industry supplier company: Giobert Spa. The primary goal is to lower costs by increasing production capacity utilization rate of the plant where the study was developed. The increase of production capacity is achieved through an adaption of the problem solving process proposed by Liker together with the Single Minute Exchange of Die method proposed by Shingo. The current plant situation and the stratification of the present losses has been assessed through the analysis conducted on data collected. The too long changeover duration has been identified as the major waste and therefore, it causes the major decrease in capacity utilization rate. It was identified through the use of WCM tools, such as 5W+1H, Overall Equipment Effectiveness indicator, Ishikawa diagram and 5 Whys. Furthermore, these tools and techniques, together with the SMED method, helped in finding the root causes of the problem and the identification of 12 possible countermeasures. This study analyzes and proposes a plan of implementation of the six countermeasures that would lead the best improvements in terms of changeover duration for the present company situation. Here, a full implementation of the proposed countermeasures would lead to a reduction in time spent during changeovers of the 72%, obtaining an estimated economical saving greater than 40000€ per year. From the results, it appears clear that WCM methodology utilization is an effective way to achieve operational cost reduction, increasing the company competitiveness.

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ABBREVIATIONS

B/C	Benefits-Costs ratio
BS OHSAS 18001	Certification of Occupational Health and Safety Assessment Series
CED	Cause-Effect Diagram
CEO	Chief Executive Officer
EEM	Early Equipment Management
EMEA	Europe, the Middle East and Africa
FCA	Fiat Chrysler Automobiles
FGA	Fiat Group Automobiles
FEM	Finite Element Analysis
ISO	International Organization for Standardization
JIT	Just in Time
MWA	Mold Waiting Area
OEE	Overall Equipment Efficiency
PDCA	Plan Do Check Act
POC	Point Of Cause
PPE	Personal Protective Equipment
SMED	Single Minute Exchange Die
SPC	Statistical Process Control
TIE	Total Industrial Engineering
TPM	Total Productive Maintenance
WCM	World Class Manufacturing

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1 INTRODUCTION

New and increasingly aggressive competitors, combined with economic downturns generate increasingly pressing competitive challenges that require industrial excellence in terms of flexibility, innovation and efficiency.

De Felice; Petrillo and Monfreda (2013) report that global competition has caused fundamental changes in the competitive environment of manufactures. Firms must develop strategic objectives, which, upon achievement, result in a competitive advantage in the market place. However, for almost all-manufacturing industry, an increased productivity and better overall efficiency of the production line are the most important goals. Most industries would like to find the recipe for the ultimate productivity improvement strategy. It often industry suffers from lack of a systematic and a consistent methodology. In particular, the world of manufacturing has faced many changes throughout the years and as a result, the manufacturing industry is constantly evolving in order to stay current and ahead of the competition.

A company properly managed must be flexible, capable to identify customer needs and expectations as quick as possible, reacting immediately according to their needs. (DEPARTMENT FOR BUSINESS INNOVATION & SKILLS, 2010).

Global competition has also expanded in the automotive industry. Until the 1970s, this industry saw increasing competition from Japanese cars, like Toyota which seemed to be able to offer better deals, in terms of quality and costs, to customers in the US and Europe. In particular, this automaker had instituted innovative production methods by modifying the U.S. manufacturing model, as well as adapting and utilizing technology to enhance production and, thus, increasing product competition. (HOLWEG, 2008).

However, innovation is not only the mode for continuous improvement even if it is particularly important mainly for continuous changes in production systems and in production technology (SANTOS SILVA et al, 2013).

Womack; Jones and Roos (1990) define this new set of techniques “lean production”. Successively excellent organizations in the world have adopted the lean model, in industry and in services, as appropriate to every operating processes, it is not strictly applicable to manufacturing only, but also to logistics, administrative, design and product development departments.

As Womack and Jones (1994) evidence the lean method goal is to “do more with less”; with less human effort, space, tools, time, and overall expense.

These changes, in turn, force organizations to develop accurate and competitive production processes and to have a proper management system. Actually, the idea of World Class Manufacturing (WCM), which inspired in an original way the principles, methods and techniques of lean production, focuses primarily on production, with a level of excellence throughout the logistics and productive cycles. In reference to the methodologies applied and the performances achieved by the best companies worldwide, is largely employed by different automakers (example: FCA group) (FIAT group, SCHIVARDI, 2014; FONSECA; DIAS; VALLE; 2014).

It is an integrated modern management model that better organizes new product development processes and manage them, and it is based on the fundamental principles of continuous improvement and eliminations of any kind of waste (PALUCHA, 2012).

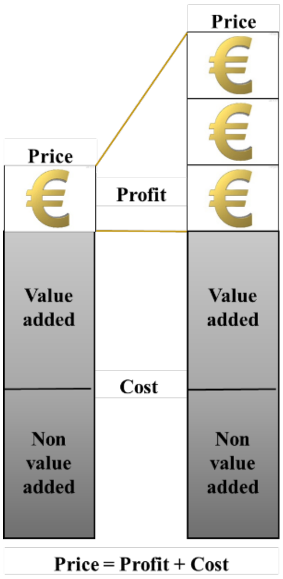
In addition one of the principal bases of the WCM methodology is the importance of involving all employees to improve the performance of the production system. As reported by Gaberding (2009):

"The essential element in order to everything working well is the human component since without full involvement of the workers nothing could be made".

Another great novelty introduced in WCM is based on the full implementation of the principles of Lean manufacturing for all the company's processes, including customers and suppliers (FONSECA; DIAS; VALLE, 2014; MAGNETI MARELLI, 2012). Generally, most automobile manufacturers require outside parts vendors to subject their component parts to rigorous testing and inspection audits similar to those used by the assembly plants. In this way, the assembly plants can anticipate that the products arriving at their receiving docks are *Statistical Process Control (SPC)* approved and free from defects.

However, in all cases the new methodology tends to make organizational changes like for example the profit vision. In the past , industry fixed the price of a product as the sum of profit and actual cost but in this way if the company wanted to increase or to maintain the same profit for coping with rising costs, it was necessary to increase the selling price and consequently to dissatisfy clients (Figure 1) (OHNO, 1988).

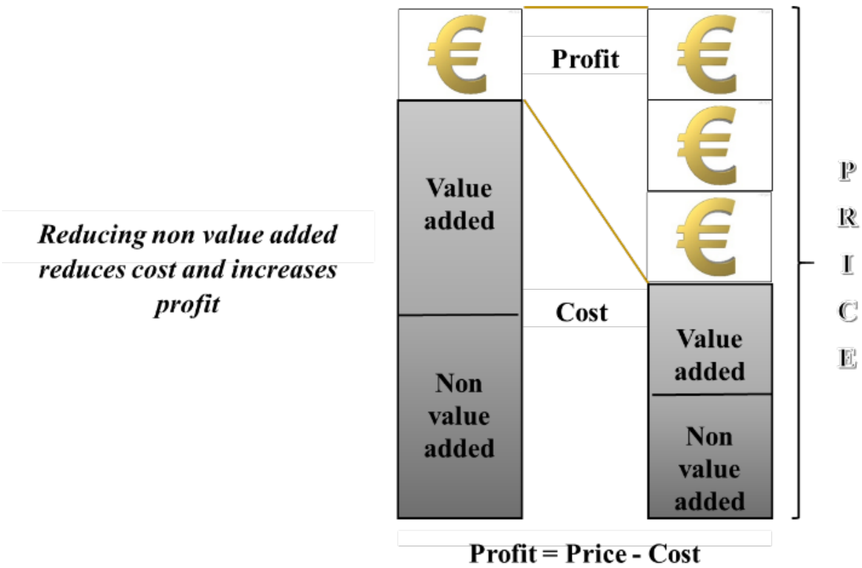
Figure 1: Profit vision in traditional method



Source: Adapted from MURGAIAH et al. (2009)

In lean method, clients define the price, as reported Ohno (1988), so that profit is the result of the difference between the selling price and the costs. In order to satisfy the client and maintaining an acceptable profit the manufacturing cost must be reduced (Figure 2). So Ohno (1988) reports: "Costs do not exist to be calculated. Costs exist to be reduced". The better mode to reduce the cost is the elimination of waste ("Muda") within a manufacturing system.

Figure 2: Profit vision in lean method



Source: Adapted from MURGAIAH et al. (2009)

In this context, the aim of this thesis is to investigate the waste reduction, in order to increase productive capacity of Giobert Company, which is an automotive industry supplier.

1.1 THE COMPANY AND THE INTERNSHIP

In this chapter are presented the Company where the internship took place and its description, including the product that produces the markets where it plays and its internal organization. After this, a short description of how the internship was developed and the problem of study of this dissertation are presented.

1.1.1 Giobert Spa. and its business

Giobert Spa. is a company that designs and produces keys and cylinder locks, door locking anti-forcing devices, and various locking devices for the automotive sector. It was founded in 1953 and is based in Rivoli, Italy, so it just celebrated its sixtieth anniversary. From its foundation, it has expanded in a first phase in Italy, building its second plant in Rivoli, then in 2007 in Poland and in 2011 in the State of São Paulo, the Brazil more productive district. Today, the Group's headquarter is located in the two Italian plants that employee about one hundred thirty people, while the Poland plant in Silesia has fifty employees and the Brazilian one in Jaguariúna thirty with the aim of reaching at least fifty employees in the next few years.

A great vantage of Giobert Company is that production, manufacturing, assembly; testing, research and development are predominantly carried out in house. In particular, Giobert designs the 90% of its products internally and carries out at least 50% of every components production in the company's plants.

Taking into account that the modern key kits comprise around one hundred components, involving twenty different processes, a great in-house workshop is important. In addition, the company, which prides itself on its vertical organization, has always carried out all its main production processes in its own plants, including Zamak die-casting, plastic injection molding and dual injection molding, die forming and key milling. The highly automated assembly lines and final testing are also in-house. In research and development fields, in which every year Giobert invests around 5% of its turnover, Product Engineering and Manufacturing Engineering divisions utilize state of the art design tools, from simulation software such as finite element method analysis (FEM) and injection molding computer-aided engineering, to rapid prototyping.

The certification of the products is also carried out on site, using a modern laboratory for testing and reliability trials.

It is remarkable to evidence a different plants work in Italy, Poland and Brazil. The Italian plants represent the Sales & Purchase Department, the Laboratory, Manufacturing and

Logistics while in Poland and in Brazil the activities performed are only of Manufacturing and Customers direct support. The principal aim of the Polish plant is assembling products for clients in Eastern Europe whereas in Brazil from 2013 provides key kits and opening devices to “Fiat Automóveis Ltda”.

In addition, it is important to evidence that all the in-house processes are carried out in a way to safeguard the environment and the health and safety of its workers, in compliance with the ethical values of the social responsibility. For this reason since 2004 the environmental management is compliant with ISO 14001, an internationally accepted standard that outlines how to put an effective environmental management system in place. In order to guarantee the health and safety of its employees and other people, the company is compliant with the standards of certification BS OHSAS 18001, which is the best benchmark for occupational health and safety management. These principles are shared by all of the Group’s employees, from Italy, Poland and Brazil, such as the belief in the continuous improvement.

The company growing and the high quality management is confirmed by the certification to ISO/TS 16949 obtained in 2012. This technique specification in fact defines the quality management system requirements for the design and development, production and, when relevant, installation and service of automotive-related products. It is often a requirement for doing business internationally in the automotive sector - not only does it help open up global business opportunities, but is now considered a robust management tool to help organizations within the industry grow, compete and succeed.

In conclusion, the principal values of the company are summarized in:

- Flexibility
- Rapidity
- Precision
- Experience
- Unity
- Talent
- Enterprise culture

All these peculiarities have caused in a market of giant multinational companies that Giobert has gained many certifications for the handling of its installations and consequently has shown to be capable of adapting to the demands of individual projects while ensuring full compliance with industry norms and technical specifications.

1.1.2 Main products

The Giobert's products can be grouped in the following families according to their use and characteristics:

- Antitheft device
- Door lock device
- Fuel cap
- Glove box latches
- Internal car door handles
- Keys
- Lock cylinders
- Lock sets
- Locking system
- Motorcycle key sets
- Steering locks with ignition switch

A sample of the main products is presented in Figure 3.

Figure 3: Giobert's products

Source: Elaborated by the author

In the following chart are presented the various product families according to their annual demand volumes (Table 1). Moreover, there is also illustrated which is the components percentage of the final products in relation to the manufacturing process. It is to highlight that are considered only the manufacturing processes carried out inside the plant where the internship took place and thus, no components bought from external suppliers are considered.

Table 1: Product Annual Volumes by Product Family

Product Family	Annual Volume (%)	Components percentage made by		
		Plastic Injection	**Zamak Die-casting**	**Blanking**
Door lock device	26%	0%	75%	15%
Keys	25%	80%	5%	15%
Internal car door handles	23%	100%	0%	0%
Glove box latches	19%	90%	0%	10%
Others	7%	10%	50%	40%

Source: Prepared by the author

1.1.3 Plant Layout

The plant layout presented in the Figure 4 presents the Corso Allamano Plant, located in Rivoli (TO). It is the plant where the internship took place and consequently where this work was developed.

Figure 4: Giobert Layout

Source: Adapted from the Giobert layout (internal document)

- Plastic Injection Unit: this area is where occurs the production of all the plastic components used by the company for the assembly of the final product. It includes ten injection molding machines of different tonnages from 100tons to 200tons, a set of plastic sprue recycling machines, one for each type of plastic used inside the company, six in total.
- Zamak Die Casting Unit: area where are located the eight die casting machines that differently from the injection ones are more standardized having all the same characteristics. The only material used for die-casting is Zamak.
- Blanking Unit: here the internal components for the automotive keys are manufactured using three different blanking machines. These are between the oldest products manufactured in the company.
- Tooling Manufacturing and Maintenance Area: every molds used in the three units described above are manufactured here. The company reduces the costs of buying the molds from an external source and permits to reduce the time needed for mold repairs and maintenance thank to this area.
- Offices: workplace of the production director that have the task to supervise the three production units, of two members of the quality departments that controls the productions periodically and of the responsible of the tooling area.
- Warehouse: the raw material of the various units is all stocked here. Here is also, where the truck are unloaded and loaded for shipments.
- Coffee Break Area: This area is dedicated to the planned breaks and for buying foods and beverages from the distributors.
- Mold Warehouses: the two mold warehouses are the stocks for the mold that are not in production of the three units.
- Production Deposit: here is where the finished product is temporarily stocked and it is transferred daily to the warehouse of finished product in the second Italian plant.

1.1.4 Injection molding

In this chapter, it is reported a description of the injection molding process. A description of only this process is provided in order to better understand which the process present in the production unit where the work is developed.

1.1.4.1 The Injection Molding Machine

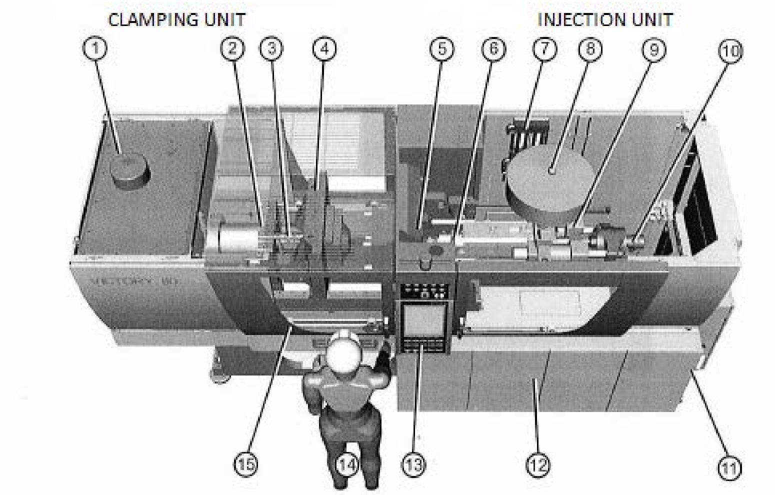
In this chapter, a brief description of an injection-molding machine is reported in order to better understand how it works and what its main components are.

In the Figure 5 is reported a picture of a molding machine of the same type of the ones present in the company.

In general, a molding injection machine has two principal components:

1. The Injection Unit: this unit melts and delivers the melt polymer to the mold. Its purpose is to liquefy the plastic materials and then inject this liquid into the mold.
2. The Clamping Unit: this unit is designed to open and close the mold properly. The clamping system is fundamental in the plastic injection process because it delivers and maintain the right pressure needed when the polymer is injected into the mold.

Figure 5: Injection molding machine description



Source: Engel machine manual

The main components listed in the Figure 5 are:

1. Hydraulic oil tank
2. Clamping cylinder
3. Hydraulic puller
4. Movable platen
5. Stationary platen
6. Injection nozzle

7. Cooling water dispenser
8. Material feed hopper
9. Injection unit
10. Screw dosing driver
11. Main switch
12. Cabinet
13. Operator panel
14. Operator workstation
15. Mobile security guard

1.1.4.2 The Injection molding process

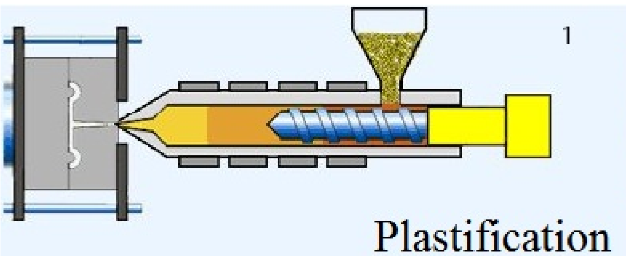
The plastic injection molding process allows the manufacture of plastic parts or components. The process works by heating and injecting material under pressure into a closed metal mold tool that is usually made of an aluminum alloy. Using a well-designed and well-made mold tool is vital in ensuring the quality of the plastic items produced.

The injection molding process can be broken down into four main stages:

1. **Plastification:**

   With the two parts of the mold clamped firmly together under pressure, plastic pellets are fed from the hopper into the barrel rotating the screw of the injection-molding machine. These plastic granules are then made into a molten plastic liquid using heat, friction and force. As the screw rotates the molten plastic is forced forward through a check valve towards the mold and by pushing the material to the front, the screw is forced backwards (Figure 6).

Figure 6: Injection molding plastification phase

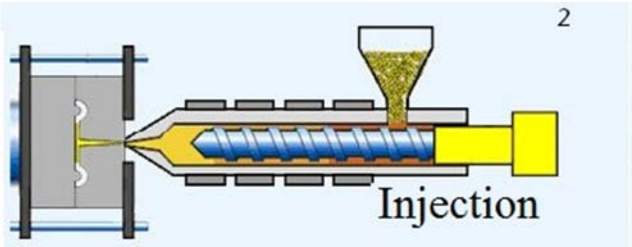


Source: XIE; SHEN; JIANG, (2011)

2. **Injection:**

A ram is used to force the screw forward so that the molten plastic material is injected into the closed mold. The pressure is applied after the molten plastic material has been injected into the mold to make sure that all the cavities and spaces have been filled (Figure 7).

Figure 7: Injection molding injection phase

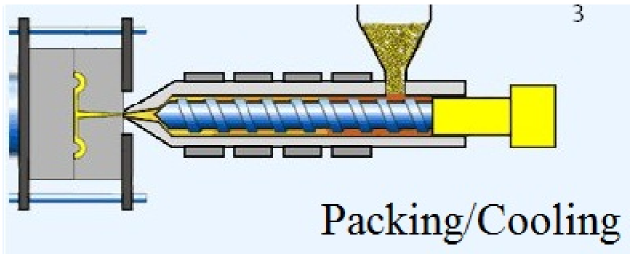


Source: XIE; SHEN; JIANG, (2011)

3. **Packing/Cooling:**

The plastic injection molding mold ids held closed under pressure to allow the plastic material to cool and set hard in the mold cavity. This stage involves some waiting time for cooling of the part. During this waiting time, the screw starts moving back for preparing molten resin for the next injection (Figure 8).

Figure 8: Injection molding packing/cooling phase

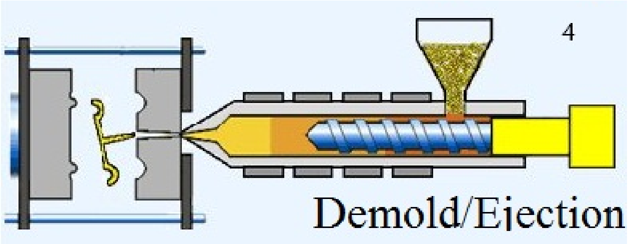


Source: XIE; SHEN; JIANG, (2011)

4. **Ejection:**

In this final stage of the process, the mold is opened and the part ejected with the help of air blast, plates, rods etc. The mold is then closed again and the whole cycle is repeated (Figure 9).

Figure 9: Injection molding ejection phase

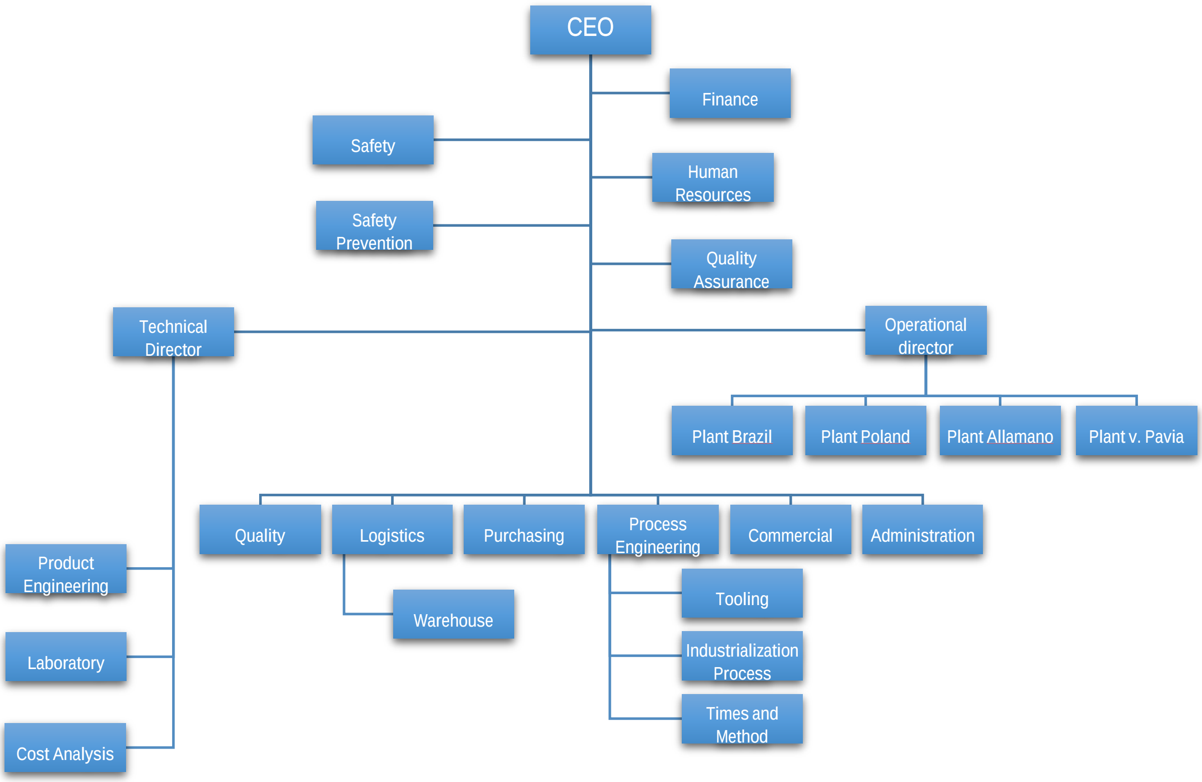


Source: XIE; SHEN; JIANG, (2011)

1.1.5 Organization chart

The organization has about 200 employees, organized according to the Figure 10. There is the owner (CEO) that controls that every function director makes its tasks properly. On one hand, there are the operative director, which is responsible for the coordination of the production of each of the four plants, and the technical director that is in charge for new product development. On the other hand, there are all the people in charge for the other departments, such as safety, finance, human resources, quality, logistics, commercial, administration etc.

Figure 10: Organization chart



Source: Adapted from the Giobert organization chart

1.2 INTERNSHIP DESCRIPTION

The internship had a duration of six months, during which I was introduced to the World Class Manufacturing. After a first week of pure formation, I entered the WCM Team as a "WCM Support"; this figure inside the company is responsible for supporting the WCM technical pillars to develop their activities. My role consisted in supporting the Focus Improvement, Professional Maintenance, Quality Control and People Development Pillars with the activities peculiar of each of them, as presented in Chapter 2.1.1.1, beside it my other role was to centralize and develop the continuous improvement activities developed in *Corso Allamano* Plant.

Among the most important activities, I developed during this period at Giobert there are the creation of a database of lesson learned, the definition and filling of the skills matrix for the WCM Team and the participation in the team responsible for the implementation of the Overall Equipment Effectiveness (OEE) indicator inside the company. In the end after its implementation, I was given the responsibility to find and select continuous improvement activities aimed at reducing wastes and thus improving the OEE.

1.3 PROBLEM DEFINITION

The problem that motivates this work is the need of Giobert to increase its profit. This as reported in Figure 2 can be done by reducing the costs incurred by the company.

Costs reduction is a central problem of every manufacturing company. Even if they have a very good product, they are not competitive in the market if they cannot produce it in an efficient and cost-effective manner.

In order to better understand the problem studied in this work, in the chapters 4.1 and 4.2 this is analyzed in more detail.

1.3.1 Objective of the work

The following work proposes a detailed analysis aimed at increasing the utilization of the Corso Allamano Plant's production capacity – where the internship took place – by identifying and reducing the biggest production losses. The continuous increase in the demand

and the market where the company operates, being an automotive industry supplier, demand an incessant search for processes improvements and losses reductions. Moreover, the company income depends principally on the ability of reducing costs being the price paid by the customers in most cases fixed or imposed.

An important aspect that was considered is that the losses reduction should be accomplished by keeping the same quality and the same lead-time. The losses reduction permits to achieve a reduction in operational costs and consequently keeping the same price it leads to a revenue increase.

As Monden (2012) supports in his book the primary purpose of a production system is the improvement of productivity achieved through the elimination of various wastes such as excessive inventory and workforce.

Moreover, a secondary objective of the work consists in achieving improvements in the utilization of the production capacity through the practical application of the tools and methods comprised by Production Engineering. More specifically, this work relies on the World Class Manufacturing principles and techniques.

1.3.2 Constraints for the work development

The aim of this work is to contribute to improve the literature about the World Class Manufacturing production system by applying its concepts and methods to a practical case in a real working environment. More precisely, the objective is to satisfy the needs of different customers of this dissertation. There are three of them each one with its own requests and constraints:

1. “Politecnico di Torino”;
2. “Escola Politécnica da Universidade de São Paulo”;
3. “Giobert Spa”.

Each of them focuses on different things. On one hand, the requests of the first two are similar and deal more with the strict application of the method and theory studied during the courses without considering too much what are the boundary conditions inside the company. On the other hand, there are the company interests, which is less interested in the strict theory application and it is more focused on reducing its costs and improving its processes without paying too much attention to the theoretical method that sometimes is redundant or simply requires resources that the company does not have.

Therefore, during the development of this work some choices had to be done according to the constraints imposed by each customer, trying to match their demands.

2 LITERATURE REVIEW

To develop this work, certain concepts and theories were the basis for the diagnosis and problem resolution developed. As the theme to be discussed is part of the macro theme of WCM, it is of great importance that some concepts are defined herein.

On the first topic, the concept of WCM system will be introduced, and how it was born. Within this topic, some important concepts that guide this system are discussed.

In the second topic, the tools and concepts used in the diagnosis of the current situation of the plant and the proposed solution will be introduced.

2.1 WORLD CLASS MANUFACTURING (WCM)

Management of manufacturing operations is a phenomenon started in the 20th century. In 1920-1930, the Ford Production System fixed the basic principles of manufacturing and management; even if Womack and Jones (2003) pointed out what Ford accomplished represented the "special case" rather than a robust lean countermeasure. Ford built his methodology for a steady state environment rather than for a continuously changing one and its dynamic conditions that nowadays firms face. In 1972, US Production System for oil crisis acutely strained while Toyota Production System shot into prominence. As Ohno (1988) observed, Japanese goods were of low cost and high quality in this period. This phenomenon was only due to the “new” principles of manufacturing process.

Flynn, Shoereder and Flynn (1999) report that Hayes and Wheelwright coined the term “world class manufacturing” and that they brought great innovations in global manufacturing philosophy.

In fact, now there is no longer focus exclusively on optimizing the processing cycle but, indeed, it is necessary to recognize the production wastes, better known as Muda, such as overproduction, waiting, transporting, inappropriate processing, unnecessary inventory, unnecessary motion and defects. These represent the bulk of the costs incurred without corresponding to any added value for the customer and therefore have to be identified and eliminated. (WOMACK; JONES; 2003)

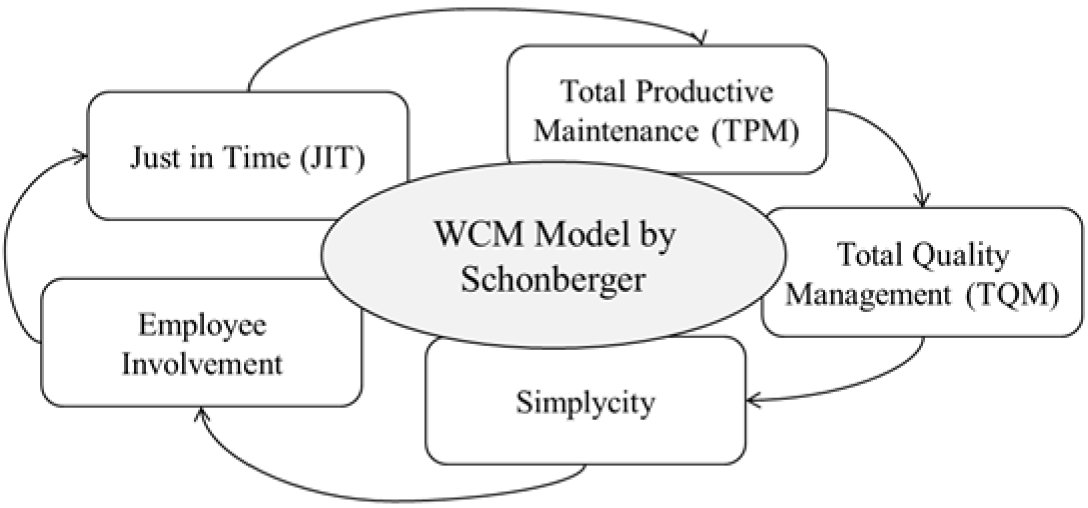
Historically, the term WCM became popular only after Schonberger declared:

“The term (WCM) captures well the breadth and the essence of the fundamental changes taking place in industrial companies” (SCHONBERGER, 1986 apud SANTOS SILVA et al., 2013 p.18).

Schonberger coined this term after having collected and analyzed many experiences of companies committed with the continuous improvement for excellence in production, with the aim to give a conceptual to the various practices and methodologies examined (SCHONBERGER, 1986).

The WCM model he ideated is illustrated here in Figure 11

Figure 11: World Class Manufacturing model by Schonberger



Source: DE FELICE; PETRILLO; MONFREDA, (2013)

Fiat Group Automobiles (FGA) redesigned the WCM model by Schonberger with the aim to change profoundly the way of producing, in order to achieve the standards of excellence of a World Class Manufacturer. According to FGA, ‘World Class Manufacturing (WCM)’ is

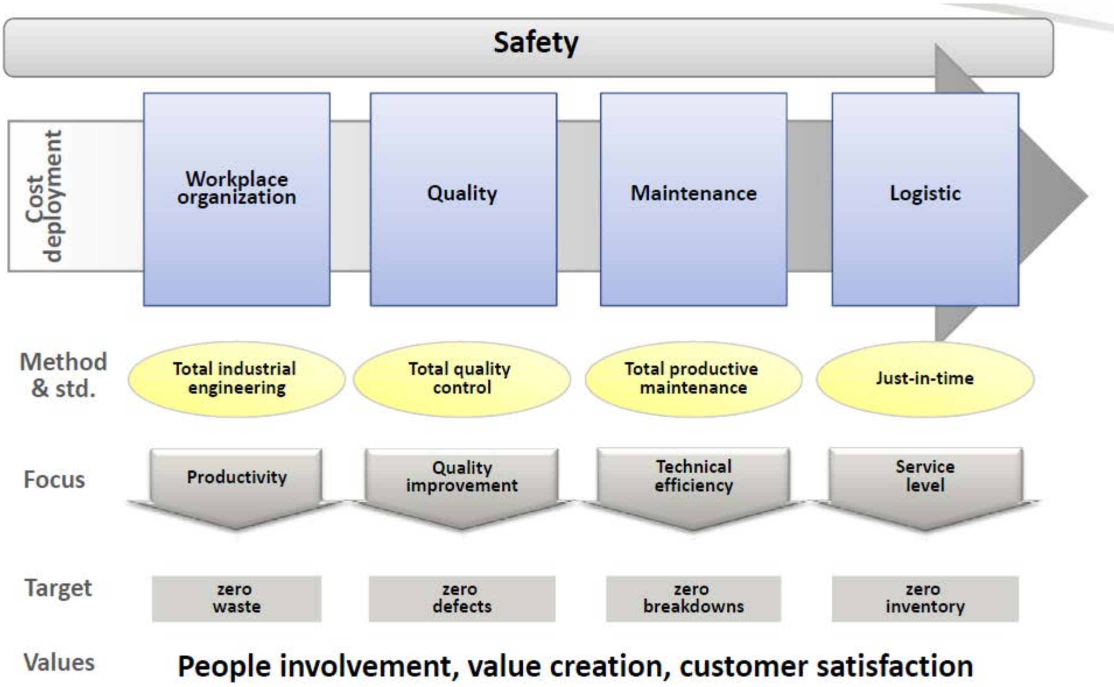
“A structured and integrated production system that encompasses all the processes of the plant, the security environment, from maintenance to logistics and quality. The goal is to continuously improve production performance, seeking a progressive elimination of waste, in order to ensure product quality and maximum flexibility in responding to customer requests, through the involvement and motivation of the people working in the establishment.” (MASSONE, 2007 apud DE FELICE; PETRILLO; MONFREDA, 2013, p.4).

Yamashina, Professor Emeritus at Kyoto Universality in Japan, contributed to the development of this new WCM model. According to him (YAMASHINA, 2009 apud COIMBRA BORGES; ARRUDA DE ABREU; VAZ, 2014, p.2), it is based on the basic concepts of:

- Total Productive Maintenance (TPM);
- Total Quality Control (TQC);
- Total Industrial Engineering (TIE);
- Just In Time (JIT).

However as the literature report (SANTOS SILVA et al., 2013; BORGES SLAVOV et al. 2013), the main innovation introduced by the WCM concerns focus on cost management through the cost deployment methodology. This methodology implies a Cost Management logic that allows connecting the improvements in quality, performance, time and services obtained through continuous improvement activities, to economic benefits of companies (Figure 12) (NETLAND, 2013).

Figure 12: World Class Manufacturing logic



Source: Giobert internal manual

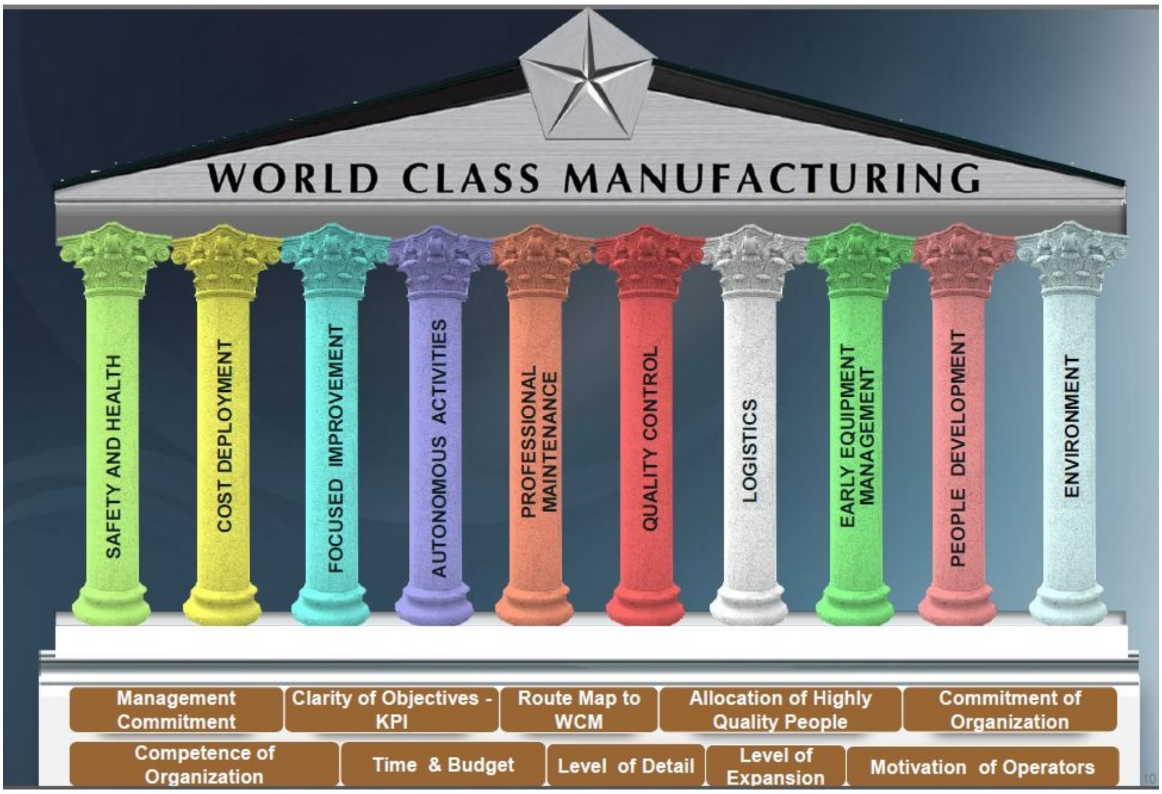
It is noteworthy that the successful implementation of WCM in recent years has caught widespread attention (SINCLAIR; ZAIRI, 2001) and this has stimulated its adoption in different countries (SALAHELDIN; EID, 1980; SOHAL, TERZIOVSKI, 2000; SVENSSON; KLEFSJO, 2000).

2.1.1 World Class Manufacturing Temple

The WCM model proposed by ex-FGA is constituted by two lines of actions for its implementation: ten technical pillars and ten managerial pillars which represent the “Temple of

WCM" (Figure 13) and points out that, to achieve the standard of excellence, a parallel development of all the pillars is necessary (MASSONE, 2007).

Figure 13: World Class Manufacturing temple



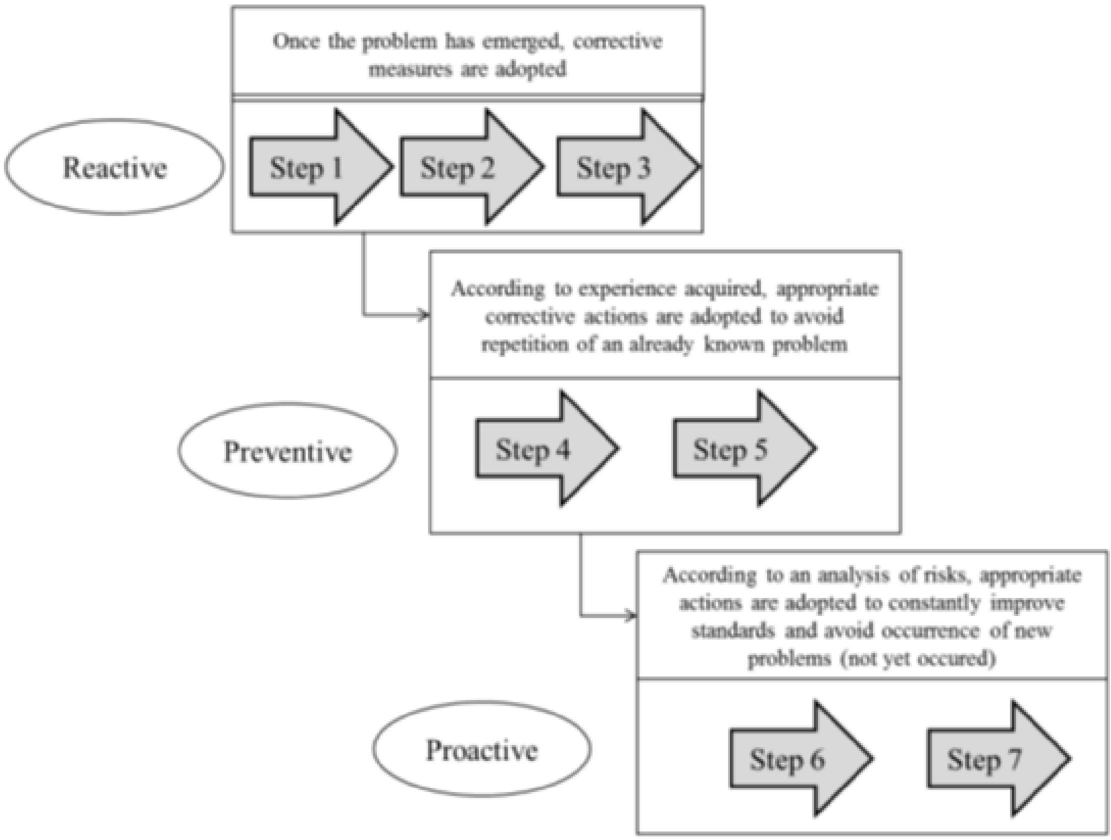
Source: Company internal material

2.1.1.1 TECHNICAL PILLARS

The Technical Pillars are developed in the deepening of the ten major aspects of production, called in order to achieve competitive advantage, based on the principle "to manufacture highest quality products at low prices".
http://www.mako.com.tr/eng/corporate/wcmworld-class-manufacturing.html).

Each pillar focuses on a specific area of the production system using appropriate tools to achieve global excellence. In particular, each of them is developed in seven steps, grouped into three different and subsequent phases, as shown in Figure 14: reactive, preventive and proactive (DE FELICE; PETRILLO; MONFREDA, 2013).

Figure 14: Seven steps approach model



Source: DE FELICE; PETRILLO; MONFREDA, 2013

Below are briefly discussed the individual technical Pillars and in the Appendix A are presented the charts with the seven implementation steps. The source used was the company internal WCM guide. (Company internal material).

- ***Safety***: The technical pillar safety is involved in the continuous improvement of the work environment and in the elimination of the critical conditions that could generate accidents and injuries. Progressively every employee has to be trained and involved in the safety culture through a sensitization process on the regulatory, economics and ethical aspects. As a result of an effective implementation of this pillar is possible to reduce drastically the number of accidents, to develop a culture of prevention to improve the ergonomics of the workplace and to develop specific professional skills.

- ***Cost Deployment:*** this pillar permits the identification, in a systematic way, of continuous improvement activities that affect reduction of losses and everything classifiable as waste or not added value. It is a key pillar since it is the starting point of the entire improvement project and the basis for all other pillars as it provides the right direction in which to move. Manufacturers can effectively evaluate which areas of the manufacturing process require improvement by using cost deployment. By breaking up the manufacturing process into smaller and smaller pieces, specific causes to losses can be identified and eliminated in order to improve production.
- ***Focus Improvement:*** The principal objective of Focus Improvement is to decrease costs by reducing major production system losses and eliminating non-value added activities. It generally employs the PDCA cycle and various problem solving tools and techniques such as 5W+1H, Ishikawa diagram and 5 Whys, in order to obtain OEE improvements, reduction of set-up time and development of a wide spread improvement. Moreover, this study will have this pillar as the point of start.
- ***Autonomous Activities:*** The autonomous activities are separated into two pillars:
    a. ***Autonomous Maintenance:*** Autonomous Maintenance is part of the activities that have the aim to prevent machine breakdowns and the micro stoppages due to lack of the maintenance of the machine standard conditions. It is a systematic approach involved to the improvement of the plant system, with the aim to manage on their own, by the operators of production, the inspection, and the control and restoring of machine conditions, eliminating the causes of dirt.
    b. ***Workplace Organization:*** Workplace organization is constituted by a set of technical criteria, methods and tools aimed at creating an ideal workplace to obtain the best quality, the maximum safety and the maximum value. This technical pillar has between its principal criteria the restoring and maintenance of the workplace conditions of order and cleanliness, the care of the operators trainings, the improvement of ergonomic conditions, the positioning of the material to the line side and the definition of the conditions of supply in order to guarantee the principle of minimum material handling.

- ***Professional Maintenance:*** The technical pillar Professional Maintenance with the Pillars of Focused Improvement, Autonomous Maintenance and Early Equipment Management are useful for the continuous improvement process of the plant technical system. Its activity is finalized to the construction of a maintenance system able to achieve zero breakdowns, zero micro stoppages of the machines, and to obtain savings, extending components life by applying predictive and corrective maintenance.
- **Quality Control:** The quality of the final product is essential for the quality management in the productive processes. The purpose of quality control is based on building the process quality with zero defects through the analysis of the capability of the process and the appropriate control of the process; it is therefore focused on the built in quality at the process rather than on a simple control of the product. Its activity is not limited only to the quality entity but has to be extended to the Production department, the Engineering department, and the suppliers and to the Purchases department.
- ***Logistics and customer service:*** The logistics as intended here with a broad and transverse vision involves three different and strictly correlated business processes: the commercial logistic, the production logistic and the procurement logistic. All of them, basically, focus on three points:
    a. Improve client satisfaction for both quality and delivery time;
    b. Reduce the costs of capital employed and of work in progress;
    c. Reduce the costs of components handling.
- ***Early Equipment Management.*** This pillar has the purpose to make plants competitive not only for technological innovation but above all for continuous improvement through the capability to prevent problems. Experience in previous machinery in start-up and in regime phases is essential in the project of new machine because it must be the basic knowledge of the production technology development. So the design review can be obtained only by a close collaboration among those involved in the plant and product design, suppliers, and maintainers.

- ***People Development:*** People development is a prerequisite for WCM implementation by encouraging employees to acquire new or advanced skills, knowledge, and viewpoints, by providing learning and training facilities, and avenues where such new ideas can be applied. In order to increase education, training centers for employees, which make use of modern technology and the later knowledge on practical training, are built. So people development allows to:
  - reset human errors
  - develop professional high level technical
  - ensure that operators have the ability to realize the maintenance in autonomous mode
  - achieve a good control of the process through the adoption of procedures of quality control
- ***Environment:*** The basic principle of the pillar Environment is the continuous improvement of the environmental performance of the productive plants.

2.2 THE CONCEPT OF LOSS (MUDA)

A loss is the use of any resource (labor, equipment, material, energy) to which is associated a cost but that does not add value. Associated with the Loss concept there is that of Waste, a type of particular loss which is in production when are employed more resources than those closely necessary for the finished product. This is in accordance to Ohno (1988) that says:

> "If it is taken into account only the work that is required as real work, the rest is defined as waste, and the following equation is true" :

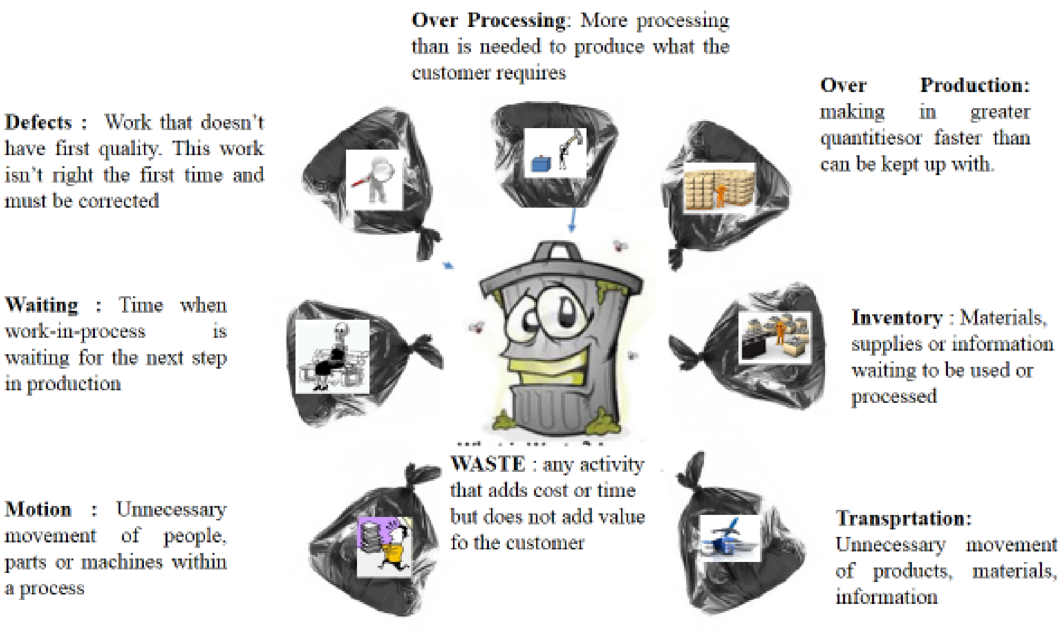
$$Present\ capacity = work + waste$$

According Ohno (1988) the real improvement comes from the factory when the waste is completely eliminated and the percentage of work is equal to 100%. Therefore, the waste have to be identified and eliminated (WOMACK; JONES, 2003; OHNO, 1988).

The wastes such as overproduction, waiting, transporting, inappropriate processing, unnecessary inventory, unnecessary motion and defects, are better known as Muda in Japanese (Figure 15).

To improve performance and quality it is necessary to individuate what kind of loss and in which level is present. In addition taking into account that the losses encountered in manufacturing environment are quite always the same, also when different company are examined, a common strategy can be realized.

Figure 15: Types of MUDA



Source: Adapted from DE BOUCORT et al. (2011)

According to Liker (2004), there is an eighth type of waste, the creativity of employees. This waste occurs when employees are not involved or listened, and as consequence, it is a loss of time, ideas, skills, improvements and opportunities.

2.3 OVERALL EQUIPMENT EFFECTIVENESS (OEE)

As previously reported, WCM in the beginning of the 21th century has become very effective because of its completeness, transparency and harmonious coherence between people and processes, between methods and techniques. It provides now the main approach to identify losses and once their causes are found, it supports their elimination, since only removing the root causes of a problem, the latter will stay away forever. This feature together with the optimization of product organization and the standardization of working methods makes this approach very important to increase equipment effectiveness, so that each equipment can be operated to its full potential and maintained at its maximum level. In order to reach this purpose it is necessary an indicator that can help to prevent unexpected breakdown, speed losses and quality defects.

This indicator is the Overall Equipment Effectiveness (OEE), which consists of a hierarchy of metrics proposed by Seiichi Nakajima (1989).

How is reported by Dal; Tugwell and Greatbanks (2000) and by Bamber et al. (2003), the concept of OEE can be applied at different levels in the manufacturing companies. In the first place, it can be used as a reference to measure the initial performance of the system. Comparing its present values with past ones it is possible to quantify the level of improvement of the measures undertaken.

In addition, the OEE can be used to make a benchmarking line of performance with those of other companies, thus highlighting any issues. Moreover, the OEE measurement, if applied to the individual phases of a process, may identify which of these phases has the worst performance, so as to allow the focusing of the TPM resources where really needed (NAKAJIMA, 1989).

If the reasons for the loss of production and the scale of the machinery problems are not fully understood, no action in the TPM optic can be undertaken to resolve them and to prevent the deterioration of the performance (BAMBER et al., 2003).

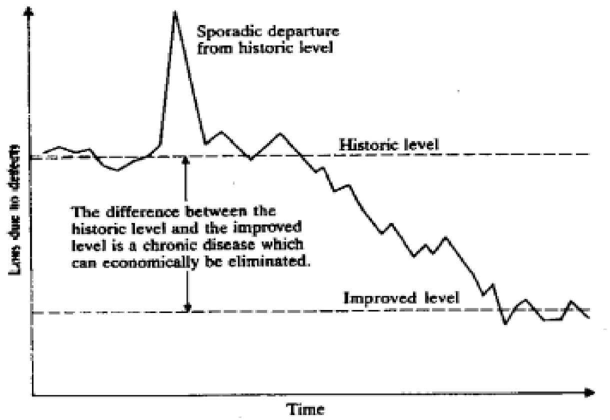
The production losses, together with the indirect costs and with the so-called hidden costs, represent for Ericsson (1997) the majority of the production costs. Nakajima (1989), therefore, identifies precisely in OEE "a method that attempts to reveal these hidden costs".

Braglia; Frosolini and Zammori (2009) also argued that for meeting the demands of an ever changing market, losses and inefficiencies in production processes must be detected and eliminated as soon as possible, starting with an analysis of efficiency indices able to evaluate the actual use of the plant than to its theoretical potential. The authors thus identify precisely in OEE the appropriate index to make such assessments.

Disturbances, according to Nord; Petterson and Johansson (1997), Tajiri, and Gotoh (1992), can roughly be divided into two categories, chronic and sporadic, depending on how often they occur. Sporadic disturbances are easily to individuate since occur rarely and in obvious mode. Chronic disturbances occur for a long time and are instead more difficult to be individuated since create a perturbation on the normal state, altering its perception. To solve them it is obligatory to compare the performance with theoretical capacity of the equipment (NORD; PETTERSSON; JOHANSSON, 1997). In Figure 16 are reported both disturbances.

However, both disturbances in the manufacturing process result in different kinds of waste or losses.

Figure 16: Sporadic and chronic disturbances



Source: JURAN; GRYNA, (2001)

OEE permits to achieve overall equipment effectiveness (Figure 17) by eliminating the six big losses (1-6) (NAKAJIMA, 1989) which can grouped in three classes (A, B, C) as following reported:

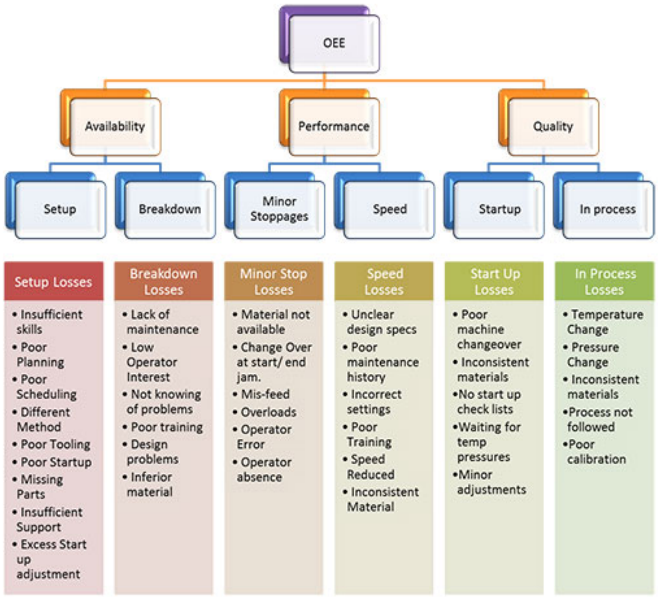
.

A. *Downtime losses*
   1. Downtime losses caused by unexpected breakdowns
   2. Setup or adjustments losses

B. *Performance Losses*
   3. Idling and minor stoppages due to equipment malfunctioning
   4. Reduced design speed of the equipment due to abnormality that results in a longer cycle time than the expected one

C. *Quality losses*
   5. Losses caused by defects and reworking of defects
   6. Reduced yield losses that occur between start-up and stable production.

Figure 17: Overall Equipment Effectiveness subdivision and six big losses



Source: Based on Ljungberg (1998)

The tool OEE that is broken down into three measuring metrics of Availability (A), Performance (P), and Quality (Q) by the following equation measures the six big losses:

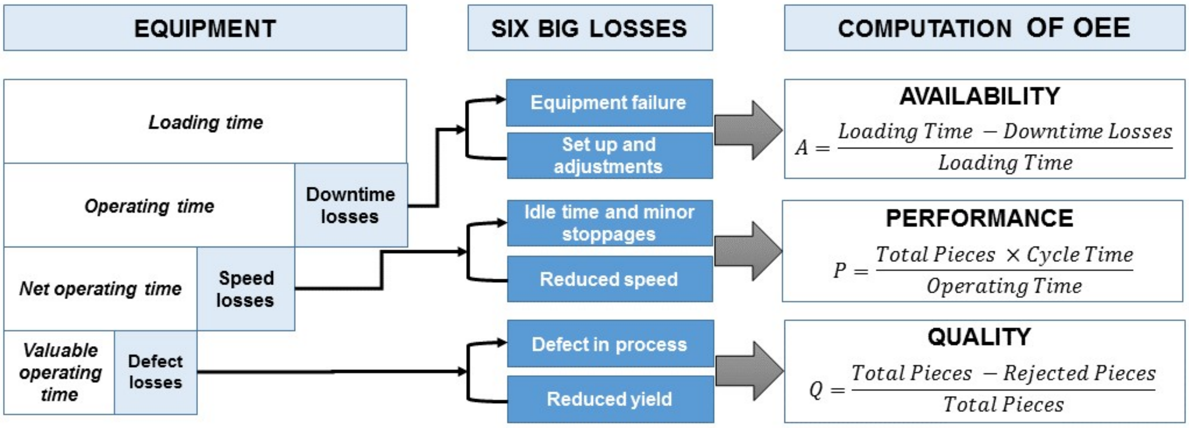
$$OEE = Availability \times Performance \times Quality$$

where Availability, Performance, and Quality are defined in the Figure 18.

OEE is so an indicator that goes from 0% to 100%. A high value of OEE indicates that machine is operating close to its maximum efficiency. However, as Busso and Miyake (2013) report, the literature found several questions about the application of OEE as overall performance indicator of manufacturing.

Jonsson and Lesshammar (1999) argued that most companies use incorrectly the Performance indicators or fail in the choice of such indicators. Although probably an objective measuring system for this parameter has not been developed yet, the authors point the need of each organization to develop its own dynamic system. In addition, the authors evidence that OEE does not consider in an integrated manner the activities, processes and functions found along the production chain. Regarding the internal efficiency, it reveals a limited view to contemplate only downtime caused by maintenance problems and production.

Figure 18: OEE breakdown and six big losses



Source: Adapted from BUSSO; MIYAKE, 2013; NACHIAPPAN; ANANTHARAMAN, 2006; BRAGLIA; FROSOLINI; ZAMORRI, 2009.

According to Braglia; Frosolini and Zammori (2009), OEE provides a good way to measure the efficiency and direct properly actions for continuous improvement when applied to either just one machine, production line or plant. When instead the scope of the improvement is broader than this, it leads to a non-optimal analysis.

Ljungberg (1998) believes that the use of the indicator OEE is useful to know the responsibility in a production area while Jeong and Phillips (2001) evidence the problem to recognize losses different from the six big losses defined before.

3 METHODOLOGY

In this chapter, the methods, tools and techniques adopted in order to develop this dissertation are presented.

The methodologies presented were chosen considering the company business and the problem of reduced capacity availability that is facing.

First, a general presentation of the Plan-Do-Check-Act cycle is presented and then a more particular application of problem solving technique is introduced. This last one represents the strategy that was followed and kept in mind along all the work development.

Then a part is dedicated to the tools utilized, highlighting the SMED method as the tool selected to face the problem of reducing the changeover time that limits the company available capacity.

3.1 PDCA CYCLE

"Different organizations use different methodologies, approaches and tools for implementing quality management and continuous quality improvement programs. In fact, each organization will certainly need to use a proper selection and combination of different approaches, tools and techniques in its implementation process. A methodology amply used is the Plan, Do, Check and Act (PDCA) cycle, that it is a convenient way to concatenate actions leading to the achievement of quality by adequacy of processes" (SOKOVIC; PAVLETIC; PIPAN, 2010)

The PDCA cycle is a decision-making management method that ensures the achieving of the goals necessary to the survival of the organization (WERKEMA, 1995).

The American Walter A. Shewhart firstly introduced this method and then W. Edwards Deming modified it in 1950, but it actually took the name of Plan-Do-Check-Act (PDCA) cycle after the Japanese recast it (MOEN; NORMAN, 2006).

"*The application of the PDCA cycle has been found more effective than adopting "the right first time" approach. Using of the PDCA cycle means continuously looking for better methods of improvement*" (SOKOVIC; PAVLETIC; PIPAN, 2010).

Cencetti (2014), head of Environment, Health and Safety Manufacturing EMEA and Global Coordination of Fiat Group Automobiles Spa declares:

"*It is obvious how the tools and methodologies proposed by WCM alone do not lead to anything if at the same time is not guaranteed the full active involvement of all the resources of the company, at different levels, and solve through the logic of the PDCA all the security breaches*".

PDCA is a cycle constituted by four basic steps (MOEN; NORMAN, 2006; SOKOVIC; PAVLETIC; PIPAN, 2010): Plan, Do, Check and Act (Figure 19).

- The first step (Plan), at the beginning of the cycle, must stabilize the objectives of a certain plan and the methods to be used.
- The second phase is that in which the processes are executed following the standard procedures and data are collected systematically.
- The third step is based on the comparison of the actual results of an action respect to those of control standards established.
- If there are no problems, the program work is maintained and standardize as new method (Act). If the difference between the two values is large, it is necessary to individuate the problem and the plan can be revised. A new PDCA cycle must be done.

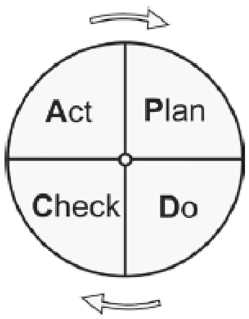
So, fully understand the nature of any problem to be solved and to develop potential countermeasures to the problem that will be tested, are the principal purpose of Plan. The problem statement must be clear and accurate, as Einstein apud Cougar (1995, p.178) said:

"If I were given one hour to save the world, I would spend 59 minutes defining the problem and one minute solving it"

Also, Kettering apud MacLean (2005) reports:

"*A problem well stated is a problem half-solved*".

Figure 19: PDCA cycle



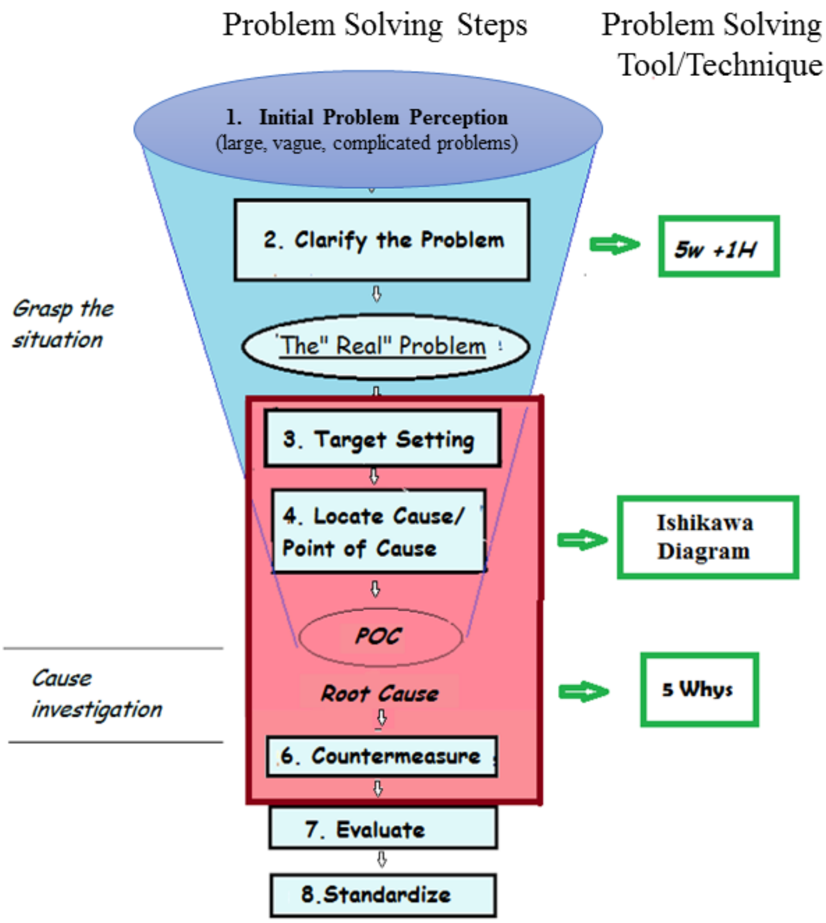
Source: SOKOVIC; PAVLETIC; PIPAN, (2010)

3.2 PROBLEM SOLVING PROCESS

Problem solving process is generally built around the PDCA cycle and it is useful when a company follows it in a systematic way (Figure 20). Once the Company identifies a symptom of a problem it must identify exactly the root causes of the problem by analyzing the current situation and a very great amount of data. At this step the use of tools such as the Ishikawa diagram, or Pareto analysis can help to prioritize among a number of possible causes and problems.

Once the problem is clarified it is necessary to make a first attempt to identify the point of cause (POC). At this step, as developed by Toyota, is very useful to employ the 5 Why tool that permits to reach the real root cause. At the successive step a countermeasure is generated and finally, if this appears effective after its evaluation, can be standardized (LIKER; CONVIS 2012).

Figure 20: Problem solving process



Source: Adapted from LIKER; CONVIS, (2012); MARKSBERRY et al. (2010); LIKER; HOUSES, (2008); OHNO, (1988).

3.3 PROBLEM SOLVING TOOLS AND TECHNIQUES

Here are presented the most important tools utilized that are present in Figure 20.

3.3.1 5W+1H

It is a logical tool of analysis used in the technique of quality improvement, with the object of guarantee that the analysis of a problem has a complete vision of all its fundamental aspects. It is applied using five basic questions: Who, What, Where, When, Which, How. These questions are very useful to understand better a particular situation and to focus on the key problems.

- The first W is **what**. What are the products/machines/equipment that are involved in the activity?
- The second W is **when**. When does the problem occur? In which phase of the process?
- The third W is **where**. Where does the problem occur? On the equipment? On the product? Etc.
- The forth W is **who**. Who perform the activity? Are the operations performed by just one operator or by more than one?
- The fifth W is **which.** Which is the frequency of the phenomenon? Is it casual or is it more frequent in some occasions?
- Then it is about **how**. How is the equipment? Is it intact?

The 5W+1H is a support to problem solving tools in clarifying the problem and helps finding the root cause of a problem, rather to collect contextual information needed further on in the process (SASAYA, 2009).

3.3.2 Ishikawa Diagram

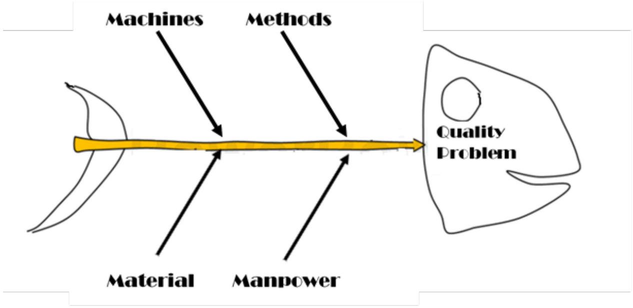
The Cause-Effect Diagram (CED), sometimes called "Ishikawa diagram" (Figure 21) because of its inventor Kaoru Ishikawa, or "fishbone diagram" due to its skeletal appearance, is used to associate multiple possible causes by category (the bones of the fish) with a single effect which represents the problem (head of the fish).

It is a tool that helps to analyze an event. It consists in listing all the possible factors that could be at the origins of an effect and successively organizing them in categories according to their origins:

- Machines

- Materials
- Methods
- Manpower

Figure 21: Ishikawa Diagram Example



Source: DOSHI et al. (2012)

According to Ishikawa (1985), it is useful to illustrate the cause-effect relation and to show which the root causes of an event are.

The Ishikawa diagram is an instrument used frequently in every PDCA phase.

In the diagnostic phase, it applied to create possible theories on the causes, in the decisional phase it helps to generate possible countermeasures and evaluate the risks related to them, and in the planning phase, it is used to forecast potential problems.

The steps to fill the diagram are:

- The definition of the problem to be solved and the prefixed objective
- Utilize a brainstorming to list all the possible causes at the origins
- Identify all the categories, elements and causes that can contribute to the considered effect
- Identify the sub-causes that can contribute to the effect and insert them in the diagram in the area we are referring to
- Continue the search until finding the real root cause of the problem
- Check carefully the validity of all the cause effect sequence.

3.3.3 5 Whys

5 Whys is a simple but effective problem solving technique that helps to identify the root causes of an abnormal phenomenon.

It is based on no fewer than five set of questions (Whys) which must be answered. In figure is reported the practical problem solving process developed by Toyota Motor Corporation and actually widely used in the world of lean development (LIKER; CONVIS 2012).

The 5 Whys analysis was the most favorite technique to resolve problems used by Ohno at the manufacturing floor. His famous example is reported below (OHNO 1988 apud MURUGAIAH et al 2009).

> ***Question 1****: Why did the robot stop?*
> ***Answer:*** *The circuit is overloaded, causing a fuse to blow.*
> ***Question 2:*** *Why is the circuit overloaded?*
> ***Answer:*** *There was insufficient lubrication on the bearings, so they locked up.*
> ***Question 3:*** *Why was there insufficient lubrication on the bearings?*
> ***Answer:*** *The oil pump on the robot is not circulating sufficient oil.*
> ***Question 4:*** *Why is the pump not circulating sufficient oil?*
> ***Answer:*** *The pump intake is clogged with metal shavings.*
> ***Question 5:*** *Why is the intake clogged with metal shavings?*
> ***Answer:*** *Because there is no filter on the pump.*

3.4 SMED

In this section is presented the particular method that is applied to the case encountered in the company: Single-Minute Exchange of Die (SMED). It is the method that best fits the necessity of the company, as shown in Chapter 4, to increase the utilization of the installed production capacity. Moreover, the SMED method when can be applied, is useful in the phases of Target setting, Locate cause/ Point of cause, Root cause and Countermeasures shown in Figure 20.

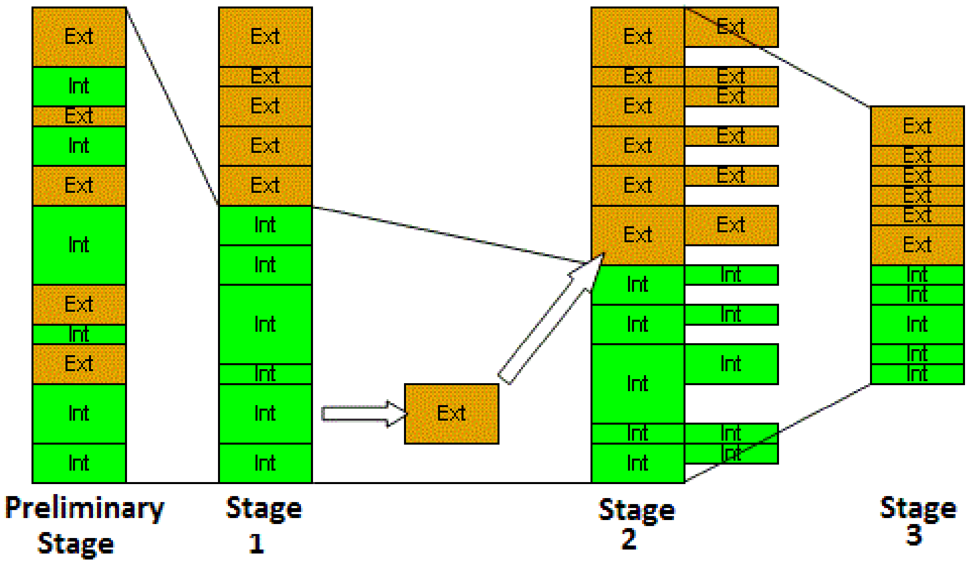
Single-Minute Exchange of Die (SMED), also known as Quick Changeover of Tools, is a method first developed by Shigeo Shingo in 1985 who defined it as a tool for setup time’s reduction that can be used in any kind of industry and machine. SMED is the theory that refers to the reduction of machine setup times and it aims to realize setups in a number of minutes that can be expressed by a single digit. Although it is not always achievable, this is the SMED method’s goal (SHINGO, 1985).

Shingo developed this method in collaboration with Taiichi Ohno to resolve the challenge to create continuous flow in small-lot production. Among all the improvements implemented to achieve continuous flow in low-volume production there was the quick tools changeover between subsequent products. (WOMACK; JONES, 2003). Before the introduction of quick changeover method, low-volume production was not feasible because in order to reduce the percentage of idle machines time per unit produced due to setup operations and thus the costs per unit produced, large production lots were used (CARRIZO MOREIRA; PAIS, 2011).

Shingo (1985) defines the SMED method implementation model through four successive stages (Figure 22):

- Preliminary stage: Internal and external setup are not distinguished;
- Stage 1: Separating internal and external setup;
- Stage 2: Converting internal to external setup;
- Stage 3: Streamlining all aspects of the setup operation.

Figure 22: SMED stages representation



Source: adapted from CARRIZO MOREIRA; PAIS, (2011)

3.4.1 Preliminary stage: Internal and external setup are not distinguished

At the beginning of the SMED, implementation there is no differentiation between the activities performed during the setup operations. Shingo (1985) proposes different techniques that can be used to study and analyze the phenomenon, such as:

- A continuous production analysis performed with a stopwatch;
- Interviewing workers to study actual conditions on the shop floor;
- Videotape the entire setup operation.

3.4.2 Stage 1: Separating internal and external setup

At this stage level Shingo (1985), after having analyzed the activities of a die changeover, differentiates between internal and external setup activities that were not distinct. The former refers to the set of activities that have to be performed when the machine is off such as the die exchange, while the latter includes all the activities that could be also done while the machine is running. According to Shingo (1985) this step can usually cut 30%-50% of the setup times by making effort to treat as much of the setup operation as possible as external setup.

3.4.3 Stage 2: Converting internal to external setup

According to McIntosh; Culley and Mileham (2000), the reduction of the internal setup time achieved in the stage 1 is not yet sufficient to reach the SMED objective. Thus, Shingo (1985) puts effort on the second stage that aims to convert internal setup into external setup. Shingo (1985) divides this activity into two steps:

- Revise the setup operations in order to identify all the activities that were wrongly assumed to be internal
- Convert them to external setup

3.4.4 Stage 3: Streamlining all aspects of the setup operation

In the majority of cases, the single digit setup time is not achieved applying stage 1 and 2; this is why Shingo (1985) proposes to streamline each internal and external setup activity. Hence, stage 3 consists in carrying out a detailed analysis of each operation with the aim to reduce its duration at the minimum. Moreover, Shingo (1985) also underlines that stage two and three can be run simultaneously. (Table 2).

Table 2: SMED phases and tool suggestions

SMED phases	Tool suggestions
Preliminary stage: Internal and external setup are not distinguished	- Analyze the Shop Floor activities in order to differentiate internal from external operations
Stage 1: Separating internal and external setup	- Use of checklists - The improvement of tool transportation
Stage 2: Converting internal to external setup	- The previous preparation of setup operations - The automation of operations - The utilization of different tools
Stage 3: Streamlining all aspects of the setup operation	- The improvement of tool transportation and warehousing - Elimination of settings, calibration and adjustments - The automation of operations

Source: adapted from CARRIZO MOREIRA; PAIS (2011) and based on SHINGO (1985)

3.4.5 SMED advantages

Beside time saved, Shingo (1985) identifies many hidden advantages of the application of the SMED method. Between them can be listed the followings:

- Increased machine work rates and production capacity
- Elimination of setup errors

- Improved quality
- Increased safety
- Lower expense
- Production in smaller lots
- Increased production flexibility
- Lower skill level requirements for setup
- New attitudes and changes in people perceptions

4 ANALYSIS OF THE CURRENT COMPANY SITUATION

In this chapter are presented the activities developed during the plan phase of the PDCA cycle described before, reminding that this usually is the longest phase of the cycle and includes the problem characterization and description, the activities planning and the study of the current situation in order to find what the problems are and what their causes could be.

More precisely the model used for the study is the one proposed by Liker (2012) and adapted for the use in Giobert presented in Figure 15. This model was followed and adapted to the present project in order to follow a well precise strategy in order to solve the problem of study.

4.1 INITIAL PROBLEM PERCEPTION

This chapter presents the situation of the company at the beginning of the study and aims at identifying which is the most critical production unit where to focus the capacity improvement project.

After a first part dedicated to how the data collection was done, the bottleneck is identified and the data analyzed in order to define the problem that will be the focus of this work.

Once the problem is defined, the project team is introduced and the targets expected to be reached within the team are identified.

4.1.1 Data Collection

The data collection process was made in two steps during the project development.

The first data collection period took place during the first two weeks of the internship experience in order to identify the production unit between the three present that was the bottleneck for the plant.

The second data collection period that lasted about two months took place in the unit identified as the bottleneck during the analysis of the data previously collected.

It is to be underlined that two sources were used:

- Data collected by the author: this includes the data collected during the direct observation of the process in production unit (Gemba). This source includes setup times, cycle times, operator displacements etc.
- Data provided by the company: this includes the data that the author could not collect directly. The productions and all the data needed for the OEE calculation were extracted from the system used inside the company; moreover, also data of costs and expected demand are part of this category.

4.1.2 Bottleneck identification

The very first step aims to find which production unit is the bottleneck of the plant in order to focus there the improvement activities. In order to perform this kind of analysis, three aspects were considered:

1. The machine utilization index
2. The Cost Deployment Matrix
3. The expected demand

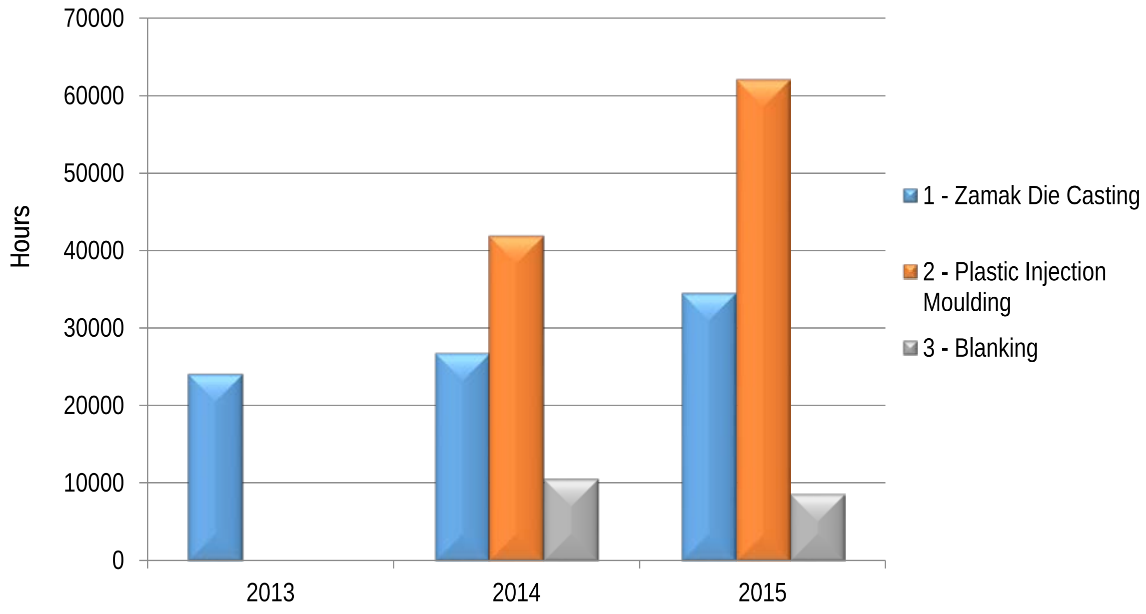
The utilization factor represents the percentage of the installed production capacity that is actually planned for production. This value is computed according to the following formula:

$$U\ [\%] = \frac{Planned\ Production\ Capacity\ [Hours]}{Installed\ Production\ Capacity\ [Hours]}$$

The installed production capacity for a working unit represents the total number of hours that all the presses of the unit can potentially work during the year, which in this case was calculated based on three shifts of eight hours per working day plus an analogue shift on Saturdays. The theoretical capacity left of Sundays and two shifts of Saturdays is not included in the computation made because as a company decision the plant stays close on these days.

The planned production capacity, instead, is the evidence of the amount of the working hours to meet the planned demand for the products. In Figure 23 it is shown the calculation of planned production capacity for the years 2013, 2014 and 2015. It can be seen that there are two values missing for the 2013 that is because the company started to keep track of these indicator just for the Zamak die-casting unit and from 2014, it has started recording it for every unit.

Figure 23: Planned production capacity



Source: Elaborated by the author

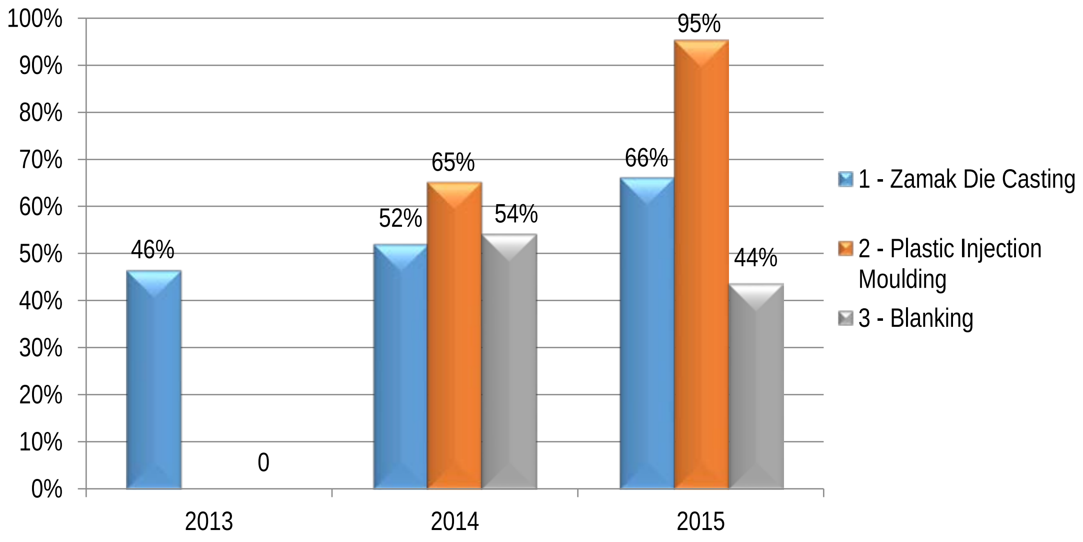
The behaviors shown in the Figure 23 already give an idea of what is the trend of the last three years. The plastic injection molding grew steeply with a 50% rate between 2014 and 2015, while the Zamak die-casting had a constant but less marked growth and the blanking presents a slight decrease.

In Figure 24, instead, the machine utilization index of the last three years is represented.

It is to highlight that are represented just the values for which was possible to collect the data. The trend shown is in line with the company strategies. It put into production many new products during the last year made mainly by plastics and, consequently, invested a lot in the plastic injection molding process.

On the other side, the Zamak die casting process had a gentle growth and the blanking process had a slight reduction but both values are still far from the plastic injection molding one that get to a utilization index of 95%.

Figure 24: Utilization index

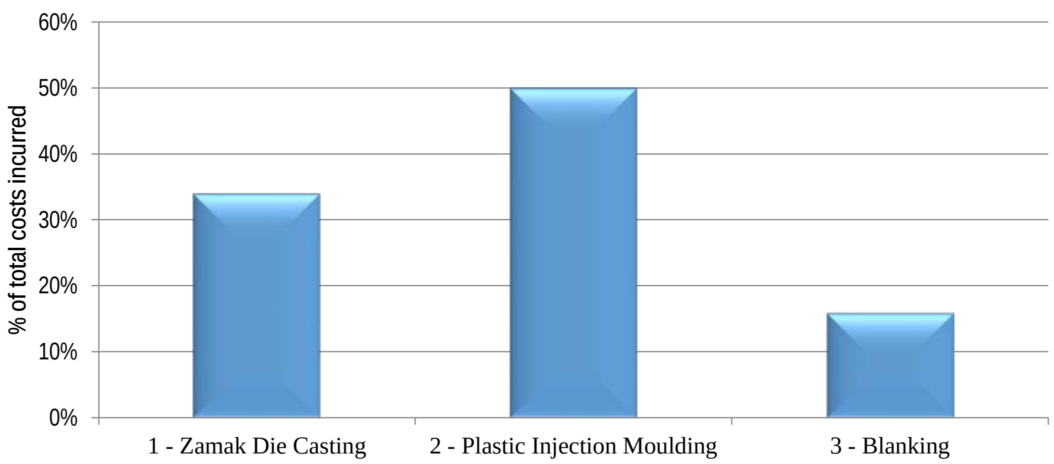


Source: Elaborated by the author

The second aspect considered in order to evaluate the bottleneck of the plant is the C Matrix evaluated by the Cost Deployment Pillar (Figure 25). This matrix is used to compute the proportion of all the losses incurred by the company in order to prioritize the improvements.

In order to estimate what are all the costs incurred by the company due to the six big losses (such as breakdowns, reworks, setup, reduced speed, small stoppages etc.) for each production unit the C matrix was used. In the Figure 25 there is the representation of the results for what concern the plant considered.

Figure 25: Cost Deployment 2015



Source: Elaborated by the author

The values shown are in percentage in order to hide possible sensible data of the company and have to be intended as the percentage of the total costs incurred in the considered plant and not as the percentage of the total costs incurred by the whole company. As it is possible to see, the plastic injection molding process is the most costly one having an expensive due to losses that is equal to 50% of the total expensive incurred in the plant and, therefore, equals the costs of the Zamak die casting and blanking together.

The third aspect analyzed in order to find the bottleneck was the expected demand for the following year.

The company is in an expansion period striving to fulfill a demand that has been steadily increasing since the beginning of the 2015 in all the production units. More precisely, for the 2016, the demand forecasts are to reach a production that is approximately 30% larger than the 2015. This increase in production is another motivation that leads to focus on the plastic unit because, despite the blanking and Zamak die-casting units, it already exploits the 95% of the capacity installed and the only way to withstand the increased demand is either by reducing the present losses or by increasing the available capacity.

The three prioritization aspects considered are report in the Table 3 in relation to their impact on each production unit. Thus, this table resumes the relative importance of each factor.

Table 3: Prioritization of the production unit

Production Unit Priority	Utilization	Cost Deployment Matrix	Expected Demand
1 - Zamak Die Casting	Not Important	Less Critical	Critical
2 - Plastic Injection Molding	Critical	Critical	Critical
3 – Blanking	Not Important	Important	Critical

Source: Elaborated by the author

It appears clearly that the most critical production unit for every of the aspects considered is the plastic injection unit.

Since the aim of this work is to improve the most critical production unit of the plant without exiting from what are the responsibilities of the production functional unit, the study developed in the next chapters will be focused on the losses reduction of the plastic unit.

4.2 CLARIFICATION OF THE PROBLEM

This chapter consists in the second step of the problem solving proposed by Liker (2012) reported in Chapter 3.2 and aims at restricting the area on which the project focuses in order to find a specific problem to be analyzed and solved.

4.2.1 Data analysis

After the identification of the bottleneck, the Overall Equipment Effectiveness (OEE) indicator is used to identify which is the most critical loss between the six big losses. In order to compute properly this indicator two months of production data are considered sufficient by the author to have a good description of the plastic unit losses dimensions.

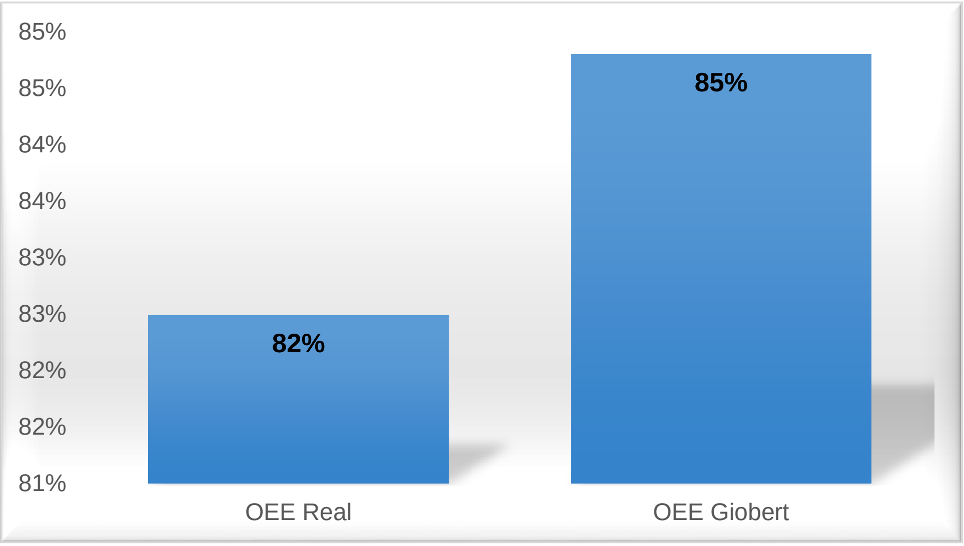
The data collection was performed during the months of October and November in 2015. The first problem that came out with the data collection was that the company adapted the OEE computation method proposed by the literature to their will. From here the decision to collect separately the data in order to compute the OEE exactly as described in the literature without changes.

The company, actually, computes an OEE that differs from its original definition one for two reasons:

- The cycle times utilized are not updated continuously and all the injection parameters modification that modify the cycle time performed by the operators are not tracked;
- The computation of the setup time is partial because the company considers as a setup just the time between the machine stopping and the die changeover, without considering into the setup the time lost due to the machine start and to produce the first good part.

In order to take care of these two problems the cycle times where recomputed when different from the ones stored in the system and the setup times were modified accordingly to their real duration. Thus, after the two months of data collection in the plastic injection molding unit the Figure 26 shows the comparison between the original OEE computed by the company and the one computed following strictly the literature

Figure 26: OEE comparison



Source: Elaborated by the author

It is evident that errors made in computation by the company lead to a slight overestimation of the OEE, in this case is of the 3%. This important aspect has to be taken into account when planning the future production based on the OEE. It means that if the company plans to produce 1000000 components, during the working year of 252 days, it will actually produce in these period 30000 components less than planned:

$$Real\ Production = 1000000\ components \times (100\% - 3\%) = 970000\ components$$

The actual days needed to complete the production are then computed:

$$Days\ actually\ needed = 252\ days \times (100\% + 3\%) = 260\ days$$

Consequently, if the production has to be delivered without delays the company will be obliged to increase the man hours spent to fulfill the plan and thus the manufacturing costs increase as well.

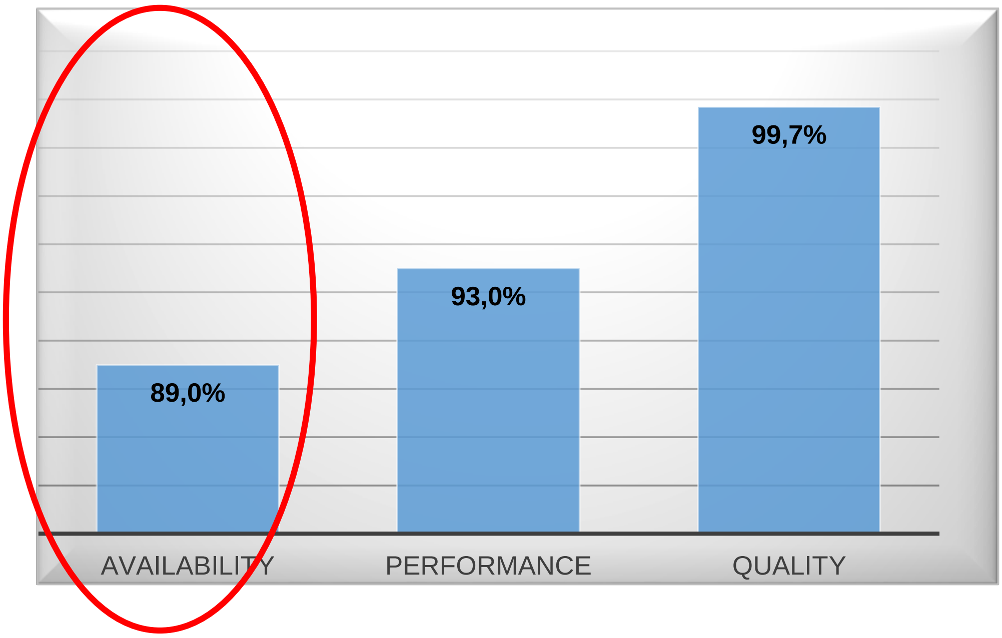
The differences from the OEE described in the literature can be justified because this is defined in general without taking into account all the particular cases that arise in a real company environment.

In this case, Giobert, being a small company, decided to avoid some data collections because these are expensive and do not give a sufficient economical return. In other words the costs of correcting the issues identified before outweigh the benefits and so is much more convenient knowing that they are present and take them into account when strictly necessary. These issues can be further analyzed but it is not the aim of this work.

The OEE indicator has it is give an idea of which is the total planned productive time lost. In the two months analyzed, the plastic injection unit produced good parts for just the 82% of time that it actually worked.

The Figure 27 gives a better idea of how this time lost is subdivided. As evident from the figure the Availability is the parameter that affects more the OEE, while there are almost no losses related to Quality and a small part related to Performance.

Figure 27: OEE subdivision analysis



Source: Elaborated by the author

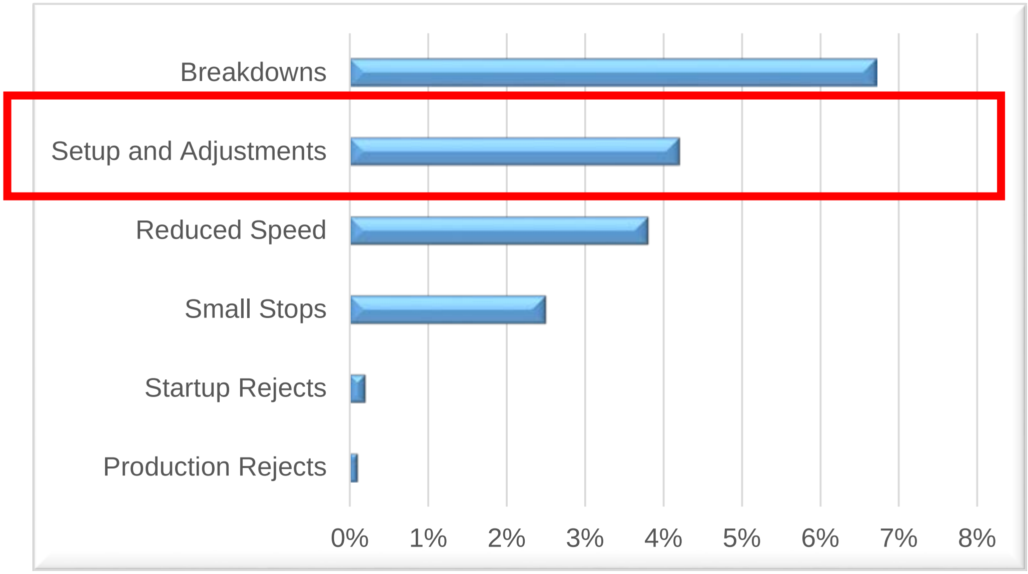
4.2.2 The "Real" problem

The data collection performed until this point is the mean through which is possible to identify the problem object of this study. The identification of the "real" problem is fundamental in order to focus on the biggest loss and thus achieve the best production improvement.

The in-depth analysis of the data collected helps to identify which is the loss that affects most the OEE and consequently the production capacity. An estimation of the time loss due to each of the Six Big Losses was computed to evaluate this aspect.

Figure 28 shows each of them in detail. The breakdowns prevail over the others with a value of almost the 7% of the planned working time and thus, from the point of view of Pareto analysis this is the first loss that has to be eliminated. Nevertheless, the next chapters will be focused on the second biggest cause of losses: Setup and Adjustments. This decision was taken together with the company under consideration because there already exists a team inside this company that is working on breakdowns elimination and thus it would be redundant deploying the same type of improvement project.

Figure 28: Pareto chart of six big losses as a percentage of the planned production capacity



Source: Elaborated by the author

4.2.3 Project team

Once the object of the study is fixed, an important step is to allocate the right resources in the project by choosing the people that will be involved with the improvement project according to their abilities.

Table 4: Project team

Team member	Project Involvement	WCM pillar
Author	Full time	FI
Operators	Support	WO,PM
Production Unit Responsible	Support	AM,PM
Machine expert	Support	EEM
Process Expert	Support	EEM

Source: Elaborated by the author

Actually, the author is the only person who is actively involved in the project but he can count on the support of all the people that can positively contribute to the result and that have a complementary knowledge with respect that of the author.

In Table 4 all the team members and their related WCM pillar of belonging are presented.

4.2.4 Project plan

The project plan is important in order to establish deadlines for each activity of the project and to align them with both the company deadlines and the team members' activities. Therefore, a detailed project plan with a GANTT diagram showing the phases of PDCA cycle and due dates was created.

The planned activities deadlines are likely to change over time and thus the project plan has to be kept uploaded with all the new events. In Appendix B is then reported the project plan developed at the beginning of this thesis project.

4.2.5 Problem description

The next step is to further analyze inside the production unit the setup time trends variations. The injection molding unit as told before has ten injection molding machine with the characteristics shown in the Table 5. It has to be noted that machine number six is missing because it was sold at the beginning of 2015 and the nomenclature has not been changed since then.

Table 5: Plastic injection unit machine description

Machine Number	Machine Manufacturer	Clamping Force [Tons]	Injection Type
01	Bodini	165	Single Injection
02	Engel	100	Single Injection
03	Engel	200	Single Injection
04	Engel	150	Single Injection
05	Engel	100	Single Injection
07	Bodini	100	Single Injection
08	Bodini	100	Single Injection
09	Engel	100	Single Injection
10	Arburg	100	Single Injection
11	Engel	100	Double Injection

Source: Elaborated by the author

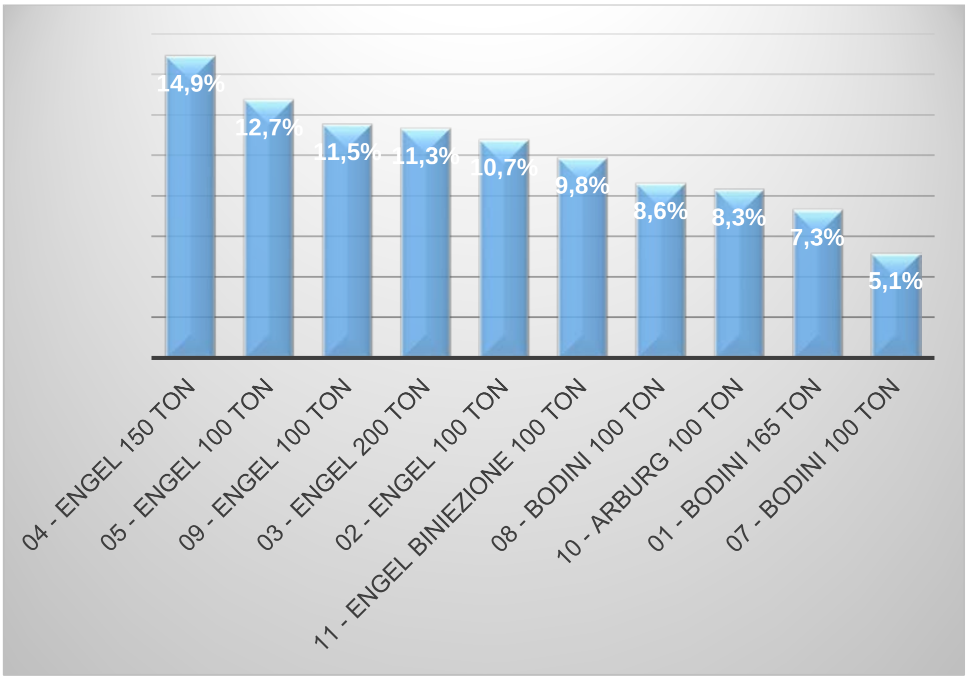
To perform this analysis was kept the same machine nomenclature utilized by Giobert.

The Pareto charts developed shows which is the percentage of the total Setup and Adjustments time attributable to each machine (Figure 29). It is evident that the machine type influences the duration of setup times. Each Engel molding machine accounts for at least 10%

of the total time wasted due to setups, while the others machine the Bodini and the Arburg account less on this loss.

Despite this, the trend inside the company is to substitute the older Bodini machines with new Engel machines and consequently making the setup a bigger problem.

Figure 29: Pareto chart of setup and adjustments per machine



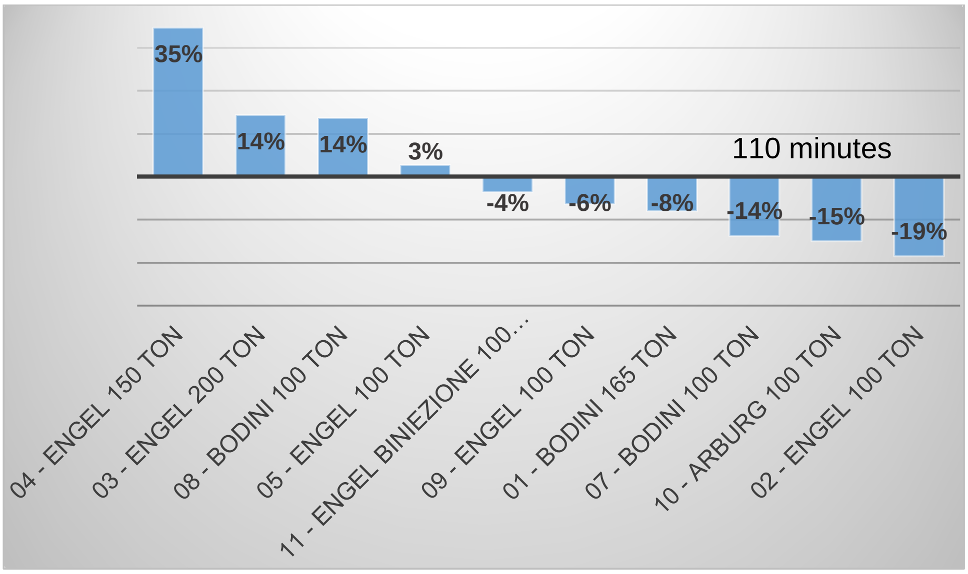
Source: Elaborated by the author

Apart from the overall time loss due to each machine, the mean setup time for each machine was computed and reported in Figure 30. This figure makes clear that beside the dependence on the machine type as shown on the previous Figure there is a strict correlation between a machine and its mean setup time. This is a consequence of the fact that most of the molds mounted on the machines numbers 2, 7 and 10 have a mold with exchangeable cavities. In other words just the cavities that give the shape to the product are changed and not the whole mold that remains screwed to the molding machine.

The exchangeable cavities allow changing the product being injected without disassembling the mold from the machine but just replacing the cavity slot. This is very helpful because permits to perform a setup in a reduced time-period, eliminating the necessity to unscrew the mold fastening elements.

Another aspect that contributes to reduce the setup mean time is the plastic material and color of the product that if have to be changed prolongs the setup time. In all the cases in which there are molds with changeable cavities the plastic material remains the same, thus achieving a further time saving.

Figure 30: Setup mean time deviation per machine



Source: Elaborated by the author

The case of the machine number 04 is the demonstration of what just said. This is the machine with the worst setup performances both for total duration and mean time. The particularity of this machine is that at every setup changes the plastic material and color and every mold it mounts do not have changeable cavities making the setup time physiologically longer than the other machines do.

Stated that the machine four is the most critical one, the study that follows will be based on this machine.

4.2.5.1 5W+1H analysis

To synthesize the problem description in order to have it always available and to give the right direction to the project a 5W+1H was developed (Figure 31).

This tool is useful as a support for the team because it contains a brief and effective description of what the problem is and its most important characteristics.

Figure 31: 5W+1H analysis

5W+1H

Problem Description: Too much time lost due setup and adjustments in the plastic unit		
What	What are the products/machines/equipments that are involved in the activity?	All the machines of the plastic injection unit are involved in the study, including all the equipments used for the setup operations.
When	When does the problem occur? In which phase of the process?	The problem occurs every time a setup is done and therefore every time a different article has to be produced
Where	Where does the problem occur? On the equipment, on the product, etc?	The problem occurs during the setup process, including the plastic injection machine, the mold and the operator that performs the setup
Who	Who perform the activity? The operations are performed by just one operator or by more than one?	The setup is performed by the mold changer and then the machine is started and the parameters adjusted by the operator responsible for the shift
Which	Which is the frequency of the phenomenon? Is it casual or is it more frequent in some occasions?	A setup is done on average every 6/7 working days on each machine
How	How Are the equipments? Are they intact?	The equipmemts and the machine at a first glance result intact and with no problems

Source: Elaborated by the author

4.3 TARGET SETTING

Before starting to analyze the setup operation itself, a target to be achieved was defined. The target definition was based on two criteria.

The first consists of a benchmarking made to see how similar companies with a similar process take for a setup operation. To this extent, the values encountered in the literature for injection molding machines with a similar tonnage of the ones analyzed are summarized in the Table 6.

The second criterion was the intention of the author to establish a "SMART" target. In other words a target that is:

- **S**pecific: The goal has to be clearly defined and without any multiples meaning
- **M**easurable: The goal has to be quantifiable in order to have a clear evidence of its accomplishment
- **A**chievable: The target has to be attainable within a given time frame and with the given resources and support
- **R**elevant: It must have an impact on the overall company strategies and goals

- **T**ime bound: It is the period within the objective has to be achieved.

Table 6: Injection molding setup time literature benchmarking

Source	Best setup time achieved [min]
DANTAS DO SANTOS et al. (2015)	20
GABAHNE; GUPTA; ZANWAR (2014)	37
KAYIS; KARA (2007)	73
COLETTI SHUCK (2014)	61
CARRIZO MOREIRA; PAIS (2011)	39
DIAS ALVES (2014)	40
VIEIRA RESENDE (2011)	50
SELAS (2012)	24
Mean setup time value	**43**

Source: Elaborated by the author

Considering the two criteria just described the setup time target was set after a meeting with the team at a mean value for the plastic injection unit of 50 minutes to be reached within the end of 2016. Consequently, according to the goal established the Table 7, showing the savings, was built.

In the table are resumed the two months of data collected and the savings that the company would achieve by reaching the 50 minutes goal. At the beginning, the mean setup time is of 150 minutes and was performed 102 times in two months, thus generating a production stop of 255 hours. The saving computed is an estimation. The machine hourly cost was estimated by the author and was set at 60€/h.

Table 7: Project target evaluation

Injection Plastic Unit (two months data)	Actual	Target	Saving	Direct Saving [€]
Mean Setup Time [minutes]	150	50	100	€ 100.00
No. Setups	102	102	0	€ -
Time spent in setup [Hours]	255	85	170	€ 10,200.00

Source: Elaborated by the author

The target achievement would make the company economize 10200€ for two months and thus annually:

$$Estimated\ annual\ saving: \frac{10200}{2} \frac{€}{month} \times 12\ months = 61200€$$

4.4 LOCATION OF CAUSES

In this chapter, the setup losses will be identified and analyzed by dividing them into external and internal activities. This activity will be performed using various tool such as the videotaping of the setup operation, the spaghetti chart and the Muda losses classification.

4.4.1 Internal and External setup activity identification

The first analysis carried out in order to identify and separate the external from the internal activities was, as suggested by Shingo (1985), the videotaping of the entire setup operation.

The videotaping was performed with the consent of the operators and it has the aim of recording all the phases and activities done during the setup, which otherwise would not result from an interview with the operators.

The Figure 32 resumes the results achieved.

Twenty-four activities were identified, of which fourteen internal and ten external, with a total setup time of 145 minutes. The total time wasted due to external activities is 42 minutes, which is almost the 30% of the total setup time.

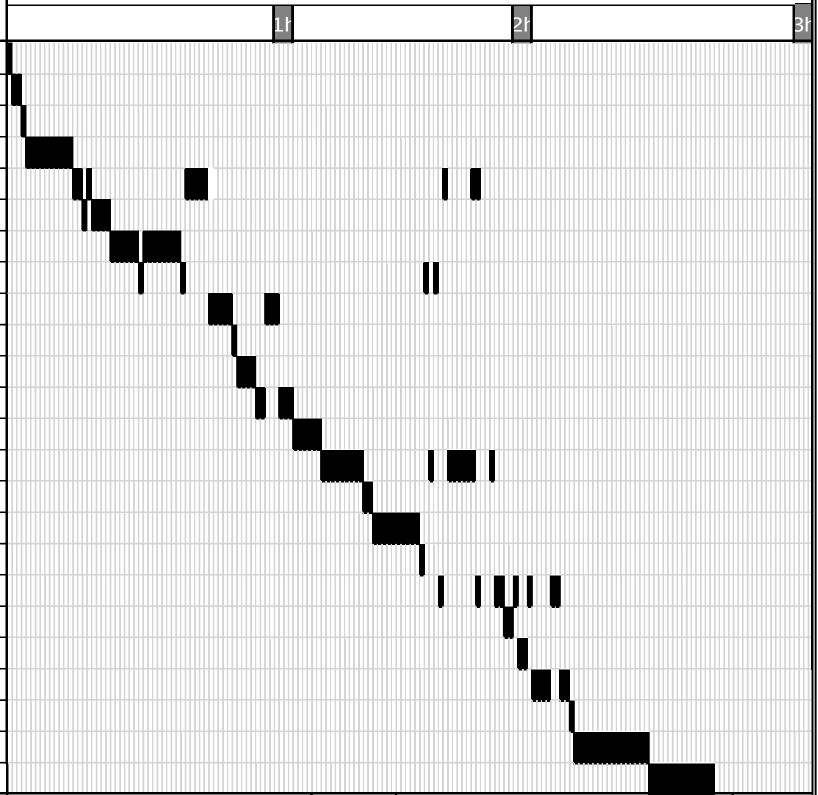
This figure also exhibits the total distance traveled by the operator during the setup, estimated in 1572 meters. This value was evaluated thanks to the spaghetti chart that is discussed below.

An important aspect of the videotaping is that it was showed to the operators during a meeting. In such way, they could realize what actually went wrong and take effective corrective actions to solve the problems that are clearly visible from the video. The operators reacted positively to this action and collaborated as much as they could to reduce the effort demand by the setup operation.

Figure 32: Setup process phases and internal and external activities identification

Nr.	Setup Process Phase	Time for type of Setup E: External I:internal			Operator
		E	I	%	
1	Machine stopping and setup preparation		0.8	1%	Op1
2	Mark stop in the production sheet	1.6		-	Op1
3	Turn off temperature controllers		0.6	1%	Op1
4	Material feed hopper cleaning		10.3	10%	Op1
5	Problems with machine safety sensors	10.8		-	Op1
6	Injector system cleaning from the previous production		4.3	4%	Op1
7	Removing and cleaning mold conditioning tubes		13.9	13%	Op1
8	Cleaning the machine	2.3		-	Op1
9	Removing mold fixers		7.6	7%	Op1
10	Fix screw eyelets on the mounted mold		1.2	1%	Op1
11	Seek the forklift	4.3		-	Op1
12	Desassemble mold from the machine		4.5	4%	Op1
13	Put back the old mold and get the new one	5.7		-	Op1
14	Mounting the new mold		15.2	15%	Op1
15	Put the forklift back in its position	1.9		-	Op1
16	10 minutes rest pause	10.0		-	Op1
17	Machine setting and program loading		1.1	1%	Op1
18	Mounting mold conditioning tubes		7.4	7%	Op1
19	Seek the cart with the tubes	2.1		-	Op1
20	Sheet molding printing at the PC	1.8		-	Op1
21	Turn on and set termoregulator		6.4	6%	Op1
22	Mark stop on the production sheet	1.3		-	Op1
23	Production start and parameter regulation		16.4	16%	Op2
24	First good part		13.7	13%	Op2
	Total [min]	42	103		

Ruler Time

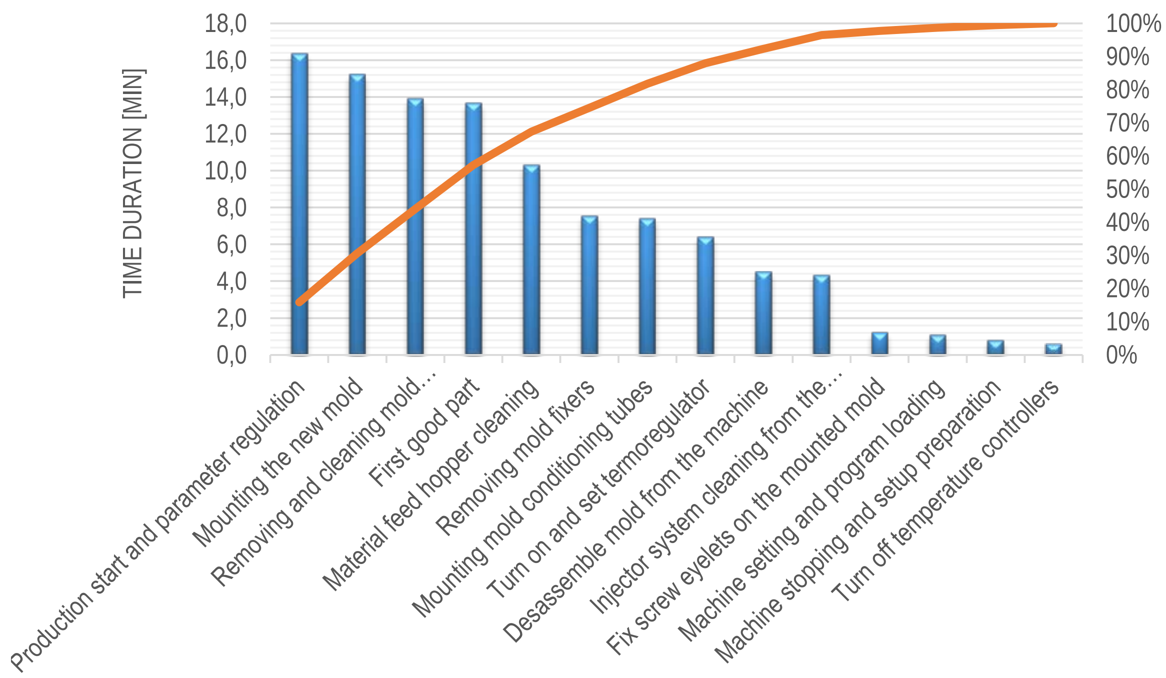


Total distance percurred: 1572m | Setup Duration [min]: 145

Source: Elaborated by the author

To better classify the internal activities a Pareto chart was used in order to give a clear evidence of which are the more durable activities. The developed chart is presented in Figure 33.

Figure 33: Pareto chart setup internal activities



Source: Elaborated by the author

The aim of the Pareto chart is to highlight the few activities that accounts for the most important losses. Usually, the 20% of the activities accounts for 80% of the losses. To this extent, this work will focus on such losses. A brief description of the activities that account for more than the 10% each of the total setup time will be provided, being the ones object of the improvement project.

- **Production start and parameter regulation (16%)**: It consists of all the settings that the operator performs on the machine panel. Every time a new production has to be started, all the injection parameters have to be implemented in the machine computer. This operation is slow because there are many parameters that have to be manually tuned until the right one is reached. This includes the setting of the mold temperature; injection temperature; injection pressure; mold opening and closing speeds; filling, holding, packing and cooling times; etc.

- **Mounting the new mold (15%):** This action includes a set of activities related with the mounting of the new mold. It is an activity performed in two steps, the movable and fixed platens fixing. First of all the mold is mounted on the fixed plate through the use of a centering ring and four clamps, then the machine movable platen is closed and fixed to the mold through the use of four more clamps.
- **Removing and cleaning mold-conditioning tubes (13%):** This activity is performed before disassembling the previous mold from the machine. It consists of cutting all the plastic ties that secures the tubes, and then to send high pressure air inside the tube channels using a valve in order to empty it from the conditioning fluid and as the last step to uncouple the tubes from both the mold and the machine.
- **First good part (13%):** This phase is a managerial decision taken with the quality department that consists in discarding the first twenty shots because the machines in the actual state cannot assure the required quality from the first shot. The time wasted due to this phase is strictly dependent from the cycle time of the components produced and thus the time presented is a mean.
- **Material feed hopper cleaning (10%):** This involves the time needed to clean the feed hopper system from the material pellets. This phase is important when there is a material and color change in the components to be produced. Moreover during the observations performed an over processing was detected during this phase due to the fact that a deep cleaning of the feed hopper is performed independently from the material and color of the next product.

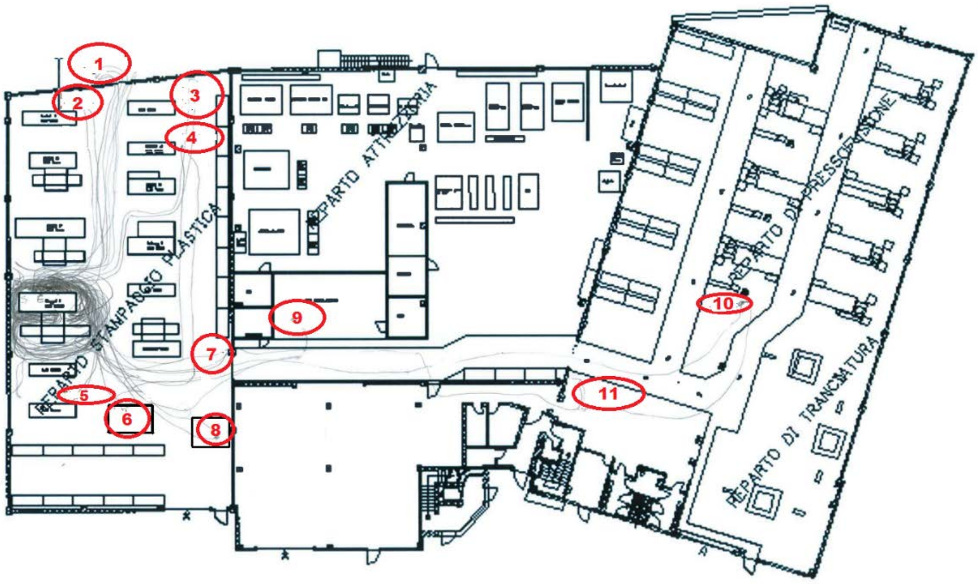
4.4.2 Spaghetti Chart

The spaghetti chart exhibited by Figure 34 was developed analyzing the videotaping in order to have a clear picture of what is the actual situation.

The operator during the setup operation should not walk so much, it is a waste and an activity that not add any value to setup. The total estimated distance traveled during the setup is 1572 meters. Considering that the average human walking pace is 5 km/h, the time wasted due to motion (MUDA) by the operator is:

$$Motion\ time\colon 1572\ meters \div \frac{5000}{60}\frac{meters}{minute} = 19\ minutes$$

Figure 34: Spaghetti chart

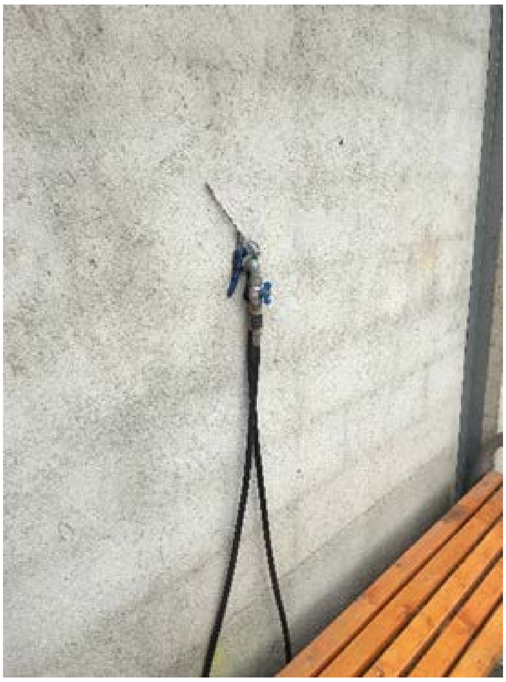


Source: Elaborated by the author

Below are listed the activities the operator performed far from the machine to better understand why he had to leave the machine.

1. Compressed air gun: During the material feed hopper cleaning (operation no.4), the operator needs to use the compressed air gun to clean a filter and it is located outside (Figure 35).

Figure 35: Compressed air gun



Source: Elaborated by the author

2. Pellet disposal: During the material feed hopper cleaning (operation no.4), the operator comes here to disposes of the pellets of the previous production (Figure 36).

Figure 36: Pellet disposal location

Source: Elaborated by the author

3. Plastic pellets deposit: here is where the operator comes to get the pellets for the new production (Figure 37).

Figure 37: Plastic pellets deposit

Source: Elaborated by the author

4. Tubes cart: The tubes cart does not have a fixed position inside the plant and the operator have to seek for it (operation No.19) (Figure 38).

Figure 38: Tubes cart

Source: Elaborated by the author

5. Stepladder: It is needed during various phases of the setup and not having a fixed position the operator waste time looking for it (Figure 39).

Figure 39: Stepladder

Source: Elaborated by the author

6. Mold waiting area: This is where the mold to be mounted is placed before the machine stopping and where the dismounted ones are deposited (Figure 40).

Figure 40: Mold waiting area

Source: Elaborated by the author

7. Trash can: Here is where the comes to throw the garbage (operation No.8)
8. PC: During the setup the operators use the computer to print the sheet with the injection molding parameters for the new product (operation No.20)
9. Forklift "deposit": Here is where the operators of the plastic unit leave the forklift after the setup (operation No.15)
10. Forklift: The operator had to come here to get the forklift (operation No.15)
11. Food distributors: while seeking for the forklift the operator stopped at the distributors to buy a coke (operation No.15) (Figure 41).

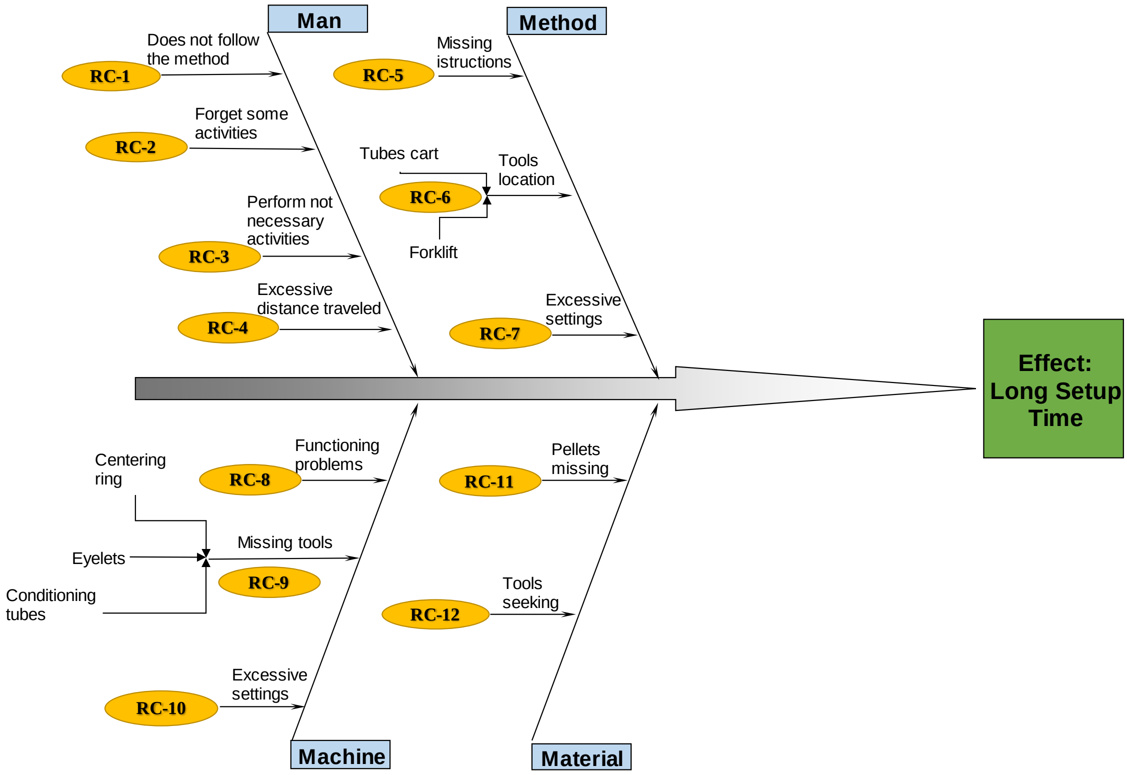
Figure 41: Food distributors

Source: Elaborated by the author

4.4.3 Basic cause and effect investigation

The fishbone or Ishikawa diagram is a very effective tool to be used in a problem solving approach. Listing all the possible causes of an undesirable effect it helps in analyzing them in a clear way.

Figure 42: Ishikawa diagram



Source: Elaborated by the author

The Ishikawa in the Figure 42 is the result of a meeting with the project team. It shows all the possible causes that lead to a long setup time that were identified by the team. During the meeting the videotapes and the SMED diagram of the Figure 32 had been two of the tools that helped most in individuating each possible cause.

In addition, the operators highlighted some problems that were not visible from the data collected and that these can cause a significant delay in the setup.

The twelve secondary causes identified are described below.

A. Man

RC-1. Does not follow the method: this is because does not exist a method to be followed and each operator acts according to his experience.

RC-2. Forget some activities: there are some operators that have less expertise due to lack of experience. This causes them to delay the activities and walk more than needed as clearly visible from the spaghetti chart.

RC-3. Perform not necessary activities: this was clearly visible from the videotape. The operator during the material feed hopper cleaning tends to the over processing loss by wasting more time than needed to clean the feed hopper.

RC-4. Excessive distance traveled: As shown in the spaghetti chart presented in Figure 34, the operator travels huge distances during the setup operations.

B. Method

RC-4. Missing instructions: From the method point of view, there are no instructions on how to perform the setup activities.

RC-5. Tools location: the tools used during the setup operation such as the tubes cart and the forklift do not have a fixed location and thus they cause the operator seeking for them causing a waste of time and an increase of the distance traveled by the operators.

RC-6. Excessive settings: the absence of a procedure causes the operators to make settings arbitrarily, such as the clamps closing load.

C. Machine

RC-8. Functioning problems: these are evident in the SMED diagram in the Figure 32. Due to an absence of preventive maintenance the functioning problems are solved when appear.

RC-9. Missing tools: The tools are not in the place where they should be and this leads the operator wasting time finding them inside the tools cart

RC-10. Excessive settings: Too much time wasted in setting the machine injecting parameters. As shown before this operation lasts 16 minutes.

D. Material

RC-11. Pellets missing: During the material change, the pellets needed are not available next to the machine and the operator has to go to the plastic pellets deposit shown in the spaghetti chart to get them.

RC-12. Tools seeking: this happens quite regularly during every setup.

5 INVESTIGATION OF ROOT CAUSES OF SETUP LOSSES AND DEVELOPMENT OF COUNTERMEASURES

In this chapter are discussed all the possible countermeasures of the problems highlighted in the previous chapter individuated by the author during a meeting with the team.

The investigation of root causes is then presented for each of the proposed countermeasure in order to justify their implementation. This process was adapted according to the point 4 and 5 presented by Liker (2012) in Figure 20.

Moreover, the countermeasures found are presented in accordance to the SMED stages division presented by Shingo (1985).

The possible countermeasures identified during the meeting are resumed in Table 8, which reports the countermeasures found, the root causes that they solve and of which step of the SMED process they are.

To select the best countermeasure they were qualitatively analyzed during the meeting and plotted on a benefit-effort chart (Figure 43). It is to be underlined that this classification was purely qualitative and based on the evaluation given by the team members’ experience. This chart is subdivided in four quadrants according to the benefits brought by the implementation of a countermeasure and the effort needed for the implementation of this countermeasure:

I. Low effort – low benefit
II. Low effort – large benefit
III. Large effort – large benefit
IV. Large effort – low benefit

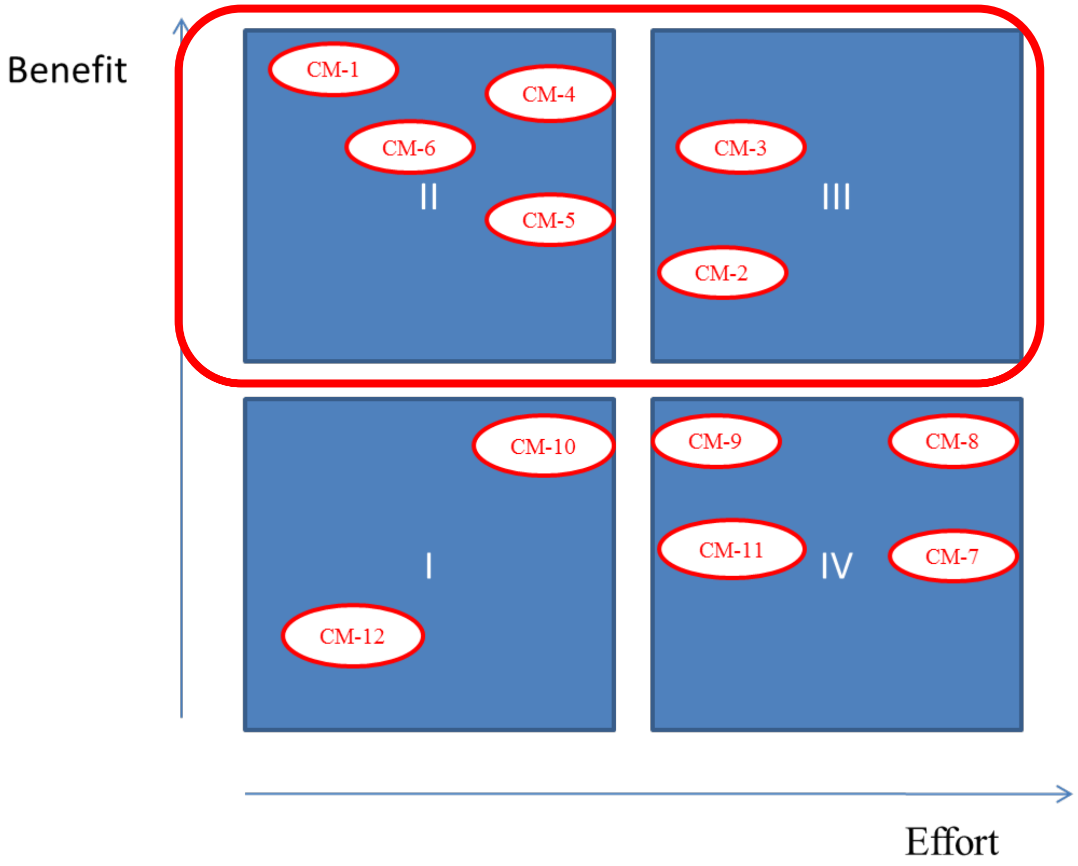
Thus, the countermeasures represented on the quadrant II are the preferred ones because they bring the more benefits with the less effort.

Table 8: Countermeasures vs Root causes

Countermeasures		Root causes		SMED
CM-1	Checklist implementation	RC-1 RC-2 RC-3 RC-5 RC-9 RC-12	Operator does not follow the method Operator forget some activities Perform not necessary activities Missing instructions Missing tools Tools seeking	Step 1
CM-2	Mold conditioning channels and tubes emptying	RC-3 RC-5	Perform not necessary activities Missing instructions	Step 1
CM-3	Mold preheating system	RC- 7 RC- 10	Excessive settings due to absence of method Machine excessive settings	Step 2
CM-4	Adjustments and regulations elimination	RC- 7 RC- 10	Excessive settings due to absence of method Machine excessive settings	Step 3
CM-5	New clamps implementation	RC- 10	Machine excessive settings	Step 3
CM-6	Two operators working in parallel	RC-4	Excessive distance traveled	Step 3
CM-7	Magnetic platens	RC- 10	Machine excessive settings	Step 2
CM-8	Overhead travelling crane	RC-6	Tools location	Step 3
CM-9	Preventive maintenance	RC-8	Functioning problems	Step 1
CM-10	5S implementation	RC-6 RC-11	Tools location Pellets missing	Step 1
CM-11	Mold height standardization	RC-10	Machine excessive settings	Step 2
CM-12	Kanban for forklift utilization	RC-6 RC-12	Tools location Tools seeking	Step 3

Source: Elaborated by the author

Figure 43: Qualitatively benefit-effort chart



Source: Adapted from ANDERSEN; FAGERHAUG; BELTZ (2010)

As a request from the company, the countermeasures further analyzed in the following chapters are the ones with a high benefit without considering the required effort and so the countermeasures in the quadrants II and III are reported below.

- New clamps implementation (CM-5)
- Mold preheating system (CM-3)
- Checklist implementation (CM-1)
- Two operators working in parallel (CM-6)
- Adjustments and regulations elimination (CM-4)
- Mold conditioning channels and tubes emptying (CM-2)

This decision was taken in agreement with the production director that wants to improve intensely the setup operation, in order to reach the objective of a 50 minutes setup within the 2016.

5.1 STEP 1 OF SMED METHOD: SEPARATING EXTERNAL FROM INTERNAL

The first and most important thing that leads in a reduction of setup times is the separation of the external activities and the internal ones. The external activities represent all those actions that can be conducted while a machine is in operation and thus without affecting the OEE.

To provide the separation it is not sufficient to highlight which are the external activities that are actually performed as internal ones but some actions have to be implemented in order to avoid this kind of problems.

The countermeasures proposed to face this issue were developed to provide a common guide to everyone that deals with setups. The aim is to avoid any type of mistake from the operators' point of view, such as the uncertainty of what actions perform before stopping the machines and the discrepancies of activities performed by different operators.

5.1.1 Countermeasure 1: Checklist implementation

The idea to implement a checklist rose during the first setup observations performed (Gemba). Right from the beginning was evident that the operators performed the setup based exclusively on their experience and perceptions and without following a proper method. This leads to different setup activities performed by each operator and it implies a loss of time due to lack of activity standardization.

The standardization of a sequence of actions in the case of a setup is important because it can help to execute each activity in the right moment without the possibility of misunderstandings.

During the analysis performed on the setup videotapes, it came out that the external activities account for forty-two minutes, representing almost the 30% of the total setup time.

In an interview with the operators, they were asked about all the activities, one by one, reported as external in the Figure 32 without letting them see the table. They responded that according to their perception the activities reported as external do not affect too much the setup time. This can be considered a proof that most of time losses due to external activities are not even perceived as a loss by the operators.

To avoid the occurrence of this phenomenon again the checklist showed in the Figure 44 was proposed as a possible countermeasure of this problem.

The checklist implementation has two main objectives:

- Standardize the sequence of setup operations: It gives the opportunity to have a clear sequence of actions that have to be performed without the need of the operator to think on what to do next.
- Operator self-control: It is a mean of control of the activities already performed and of those that have to be executed.

The operations performed during the setup and showed in the checklist were divided into four groups:

- **Operations to be done before the machine stops**: in this category are included all the activities that can be performed independently from how much time is missing from the setup beginning
- **Operations to be done right before the machine stops**: this includes all the actions that are important to be performed as last ones because they can affect other things, for example, the forklift and the carts may be needed from someone else.
- **Operations to be done during the machine stop**: These activities will actually influence the setup time and capacity utilization. These are the internal activities.
- **Operations to be done when the machine is right back to work**: Operations performed after the machine is back to work that can be executed only after the setup ends.

This countermeasure is simple to be implemented because it only requires the time for instructing the operators using the checklist. Moreover, it does not demand an investment to be implemented and this means that is an optimal countermeasure from the company point of view, considering that no costs are involved.

The maximum benefit that can be reached with a full understanding and utilization of this checklist is up to 42 minutes in time saving during the setup operations. This benefit is considered as if all the external activities are fully performed as external and not as internal.

The potential increase in production capacity during a working year if this countermeasure is applied to every setup and machines can be as high as 428 hours per year.

$$Production\ capacity\ gain\ countermeasure\ 1 =$$

$$= 612\,\frac{setup}{year} \times 42\,\frac{minutes}{setup} \times \frac{1}{60}\frac{hour}{minutes} = 428\,\frac{hours}{year}$$

Figure 44: Checklist proposed

Setup Check List			
	Check Items	**Descriptions**	**Status**
1	**Operations to be done before the machine stops**		□
1.1.0	Check the next needed production	Check on the system which is the next item that have to be produced	□
1.2.0	Place the mold in the mold waiting area	Take the mold that have to be mounted and put it in the mold waiting area	□
1.3.0	Prepare the tools needed for the setup		□
1.3.1	- Eyelets		□
1.3.2	- Wrenches Nr. 24 and 19		□
1.3.3	- Torque wrench		□
1.3.4	- Mold fixers		□
1.3.5	- Tube valves		□
1.3.6	- Scissors		□
1.3.7	- Allen set		□
1.3.8	- Pliers		□
1.3.8	- Female torx screwdriver		□
2	**Operations to be done right before the machine stops**		□
2.1	Place the forklift close to the machine	Seek for the forklift and bring it near by the machine	□
2.2	Place the tubes cart close to the machine	Seek for the tubes cart and bring it near by the machine	□
2.3	Place the tools cart close to machine	Bring the tools cart previously prepared for the setup close to the machine	□
2.4	Print new product molding parameters sheet	Sheet containing all the injection molding parameters and data on the production to be performed	□
2.5	Put everything in order in the machine area	Be sure that nothing prevent the forklift from passing	□
2.6	Mark stop start on the production sheet	Fill the production sheet with setup start time	□
3	**Operations to be done when the machine is not running**		□
3.1	Injection system cleaning	Clean the injector system from the material of the previous production	□
3.2	Material change	When needed change the material used according the production	□
3.3	Mold changeover	Disassemble mold of the previous production and mount the new one	□
3.4	Parameters tuning	Setting parameters and temperatures	□
3.5	Start production	Discard first 15 shots	□
4	**Operations to be done when the machine is right back to work**		□
4.1	Mark stop end on the production sheet	Fill the production sheet with setup end time	□
4.2	Clean and put in order the machine area		□
4.3	Put each tool used back in its place		□

Source: Elaborated by the author

Thus, the maximum economical savings can be calculated as:

$$Saving\ Solution\ 1 = Production\ capacity\ gain \times Machine\ hourly\ cost$$

$$= 428 \frac{hours}{year} \times 60 \frac{€}{hour} = 25680 \frac{€}{year}$$

5.1.2 Countermeasure 2: Mold conditioning channels and tubes emptying

The mold conditioning tubes cleaning described in the section 5.3.1 is performed through the two tools showed in the pictures 45 and 46.

Figure 45: Pressure valves

Source: Elaborated by the author

The pressure valve (Figure 45) is attached to the tubes in order to have a connection interface with the air compressed gun (Figure 46). Since these valves work under pressure, when compressed air is sent inside the channel these open and allow the fluid exiting from the opposite end of the tube. The fluid is then collected in a plastic bucket and disposed.

Figure 46: Air Compressed gun next to the injection molding machine

Source: Elaborated by the author

This activity on the moment is performed as an internal activity while the machine is not running because, as the operators said, it would lead to an increase of working effort if performed as an external one. This is because at the actual state of things inside the company there are not the tools necessary to execute this cleaning in a simple way.

Introducing a mold transporter as the one shown in the Figure 47 that can accommodate one mold this activity could be simplified and transformed in an external one.

The model shown in Figure 47 is the Rico's "walk behind transporter". The selection between the models available was made according to the requirements described and to the space available inside the plant that being not too large it cannot accommodate bigger transporters.

The countermeasure proposed consists in leaving the tubes mounted on the mold and in transferring the mold on the cart once disassembled from the machine and leaving it there until the setup is done.

After the machine has restarted, the operators can bring the movable cart with the mold on top close to the machine and utilize the same air compressor gun located next to each machine in order to provide a proper cleaning of the mold and tube channels.

Figure 47: Rico's Walk behind transporters

Source: http://www.ricoequipment.com/engineered-models/transport-agvs/walkie-transporter/

Using the procedure the activity of emptying the mold and tubes channel can be executed while the machine is running and thus without limiting the production capacity.

Moreover, the mold transporter gives the company other benefits beside the one described above as shown in countermeasure 3.

In addition, the activity described in the point 1.2.0 of the checklist “place the mold in the mold waiting area (MWA)” can be further improved by placing the mold on the mold transporter instead that in the mold waiting area. Doing so, the time needed for transferring the mold from the MWA to the machines can be reduced by placing the mold transporter next to the machine before stopping it.

A drawback of the countermeasure described is the increase in maintenance effort that the purchase of the new transporter causes. Even if the maintenance needed for this does not demand excessive costs and operators working hours, it has to be taken into account as well.

The benefits achieved by implementing this countermeasure can be evaluated as the time saved in the channels cleaning procedure that accounts approximately for 5 minutes and the time saved for mold transport that is dependent from the distance between the machine and the MWA that on average is about 2 minutes.

$$Production\ capacity\ gain\ countermeasure\ 2 =$$

$$= 612\,\frac{setup}{year} \times 7\,\frac{minutes}{setup} \times \frac{1}{60}\frac{hour}{minutes} = 71\,\frac{hours}{year}$$

Thus, the maximum economical savings can be calculated as the net difference between the costs incurred and the benefits achieved. The costs of buying the mold transporter were estimated in 15000€ and considering a 5-year depreciation, they were considered as 3000€ per year.

$$Saving\ Solution\ 2 = Benefits - Costs$$

$$= (Production\ Capacity\ gain) \times (machine\ hourly\ cost) - Depreciation\ cost =$$

$$= 71\,\frac{hours}{year} \times 60\,\frac{€}{hour} - 3000€ = 1260\,\frac{€}{year}$$

5.2 STEP 2 OF SMED METHOD: CONVERTING INTERNAL TO EXTERNAL SETUP

This chapter contains the proposed countermeasures to convert internal activities to external ones. This stage was a consequence of the previous one since it was not sufficient to reduce the setup time as much as planned.

In order to identify further countermeasures that were not identified before, the entire setup process was reexamined. Every single operation was analyzed again in order to find the ones that were assumed internal during the first analysis.

The most important aspect of this phase was to look at the activities with a new perspective different from the previous one and not bound by old habits.

Once the analysis was performed, the problem was to find ways to convert these activities into external ones. The countermeasures found are then presented.

5.2.1 Countermeasure 3: Mold preheating system

As a result of the analysis the activity named as "first good part" (operation No.24) was identified as a big loss of the setup operation, accounting on average for the 13% of the total internal setup time.

This operation is decided and defined by the quality department in order to guarantee the expected quality of the product. It includes the average time needed for twenty injections that are discarded at the machine startup. This value is strictly correlated to the product cycle time and as a consequence it can vary from less than ten minutes up to thirty minutes.

The five whys tool was used to better understand the problem and to find its root cause. It consists in an iterative process by asking why of a problem iteratively in order to explore the cause-effect relationships and to find out what is its root cause.

The five whys used are reported below:

1. **Why** is this time needed for producing the first good part?

   Because it is needed to discard the first twenty injections

2. **Why** have the first twenty injections to be discarded?

   Because the quality department stated it

3. **Why** did the quality department state it?

   Because the machine cannot assure quality before twenty injections

4. **Why** do the machines not assure quality?

   Because they need time to reach the working temperature

5. **Why** do they need time to reach the working temperature?

Because the mold is not preheated when the machine starts the production.

The application of this tool led the time to identify which is the root cause responsible for this loss. In the actual setup process the mold heating is performed when the machine is started delaying the production of the first good part.

The countermeasure proposed consists in implementing in the plastic unit department a mold preheating system. Taking into account that both the costs and the space available inside the department do not allow to buy a mold-preheating oven, the countermeasure proposed consists in utilizing the tools already available inside the company and the mold transporter introduced with the countermeasure 2.

The countermeasure is to create an insulating support that would accommodate the mold on the mold transporter by insulating it from the transporter. Then the second step is to take advantage of the time that the mold pass next to the machine waiting for the setup by connecting it to the mold temperature controllers that are present next to every machine such as the ones in the Figure 48 through the use of the mold conditioning tubes.

Figure 48: Mold thermoregulators

Source: Elaborated by the author

After that this operation is performed a valve can be used to provide the mold the right temperature of the fluid sent into its channels in order to preheat it until the prescribed temperature.

The major drawback of this countermeasure is the safety issue since the operators now are used to handle the molds at ambient temperature. Starting handling molds at about 100°C can be dangerous for their safety if they are not trained and not provided with the right personal protective equipment (PPE).

The insulating support building, instead, is not a big issue for the company since they are provided with a well-equipped tooling area where they manufactured almost every tools that are used inside the company. Moreover, this is a big advantage since permits to reduce costs drastically and allows modifications if needed.

The benefits achieved by implementing this countermeasure can be evaluated as the time saving achieved through the mold preheating that accounts approximately for 10 minutes.

Another advantage of this countermeasure that will not be considered in the calculation is that it reduces the scrap production at startup, increasing slightly the Quality indicator and consequently reducing the costs associated with the production of non-valuable products.

$$Production\ capacity\ gain\ countermeasure\ 3 =$$

$$= 612\frac{setup}{year} \times 10\frac{minutes}{setup} \times \frac{1}{60}\frac{hour}{minutes} = 102\frac{hours}{year}$$

Then the maximum economical savings can be calculated as well.

$$Saving\ Solution\ 3 = Benefits - Costs$$

$$= (Production\ Capacity\ gain) \times (machine\ hourly\ cost) - Total\ costs$$

$$= 102\frac{hours}{year} \times 60\frac{€}{hour} - 1700€ = 4420\frac{€}{year}$$

The costs incurred are resumed in the Table 9.

Table 9: Countermeasure cost elements

Item		Cost
Operators training	€	500.00
Manufacturing support	€	800.00
Others (material, PPE, etc.)	€	400.00
Total Costs	€	1,700.00

Source: Elaborated by the author

In the table, the costs due to the purchase of the mold transporter were not included because they were already taken into account in the second proposed countermeasure. Finally, the total annual savings of this countermeasure can be computed.

5.3 STEP 3 OF SMED METHOD: STREAMLINING ALL ASPECTS OF THE SETUP OPERATION

In this chapter are presented the deep studying done on every single activity in order to further reduce their duration. The detailed analysis of each elemental operation permits to achieve new important improvements.

To this extent, the countermeasures found to eliminate the adjustments, implement parallel operations and using functional clamps are presented below.

5.3.1 Countermeasure 4: Adjustments and regulations elimination

The adjustments were identified as the first cause of time waste during the setup. These are all concentrated during the parameter regulations at the machine startup.

The time spent during this phase is due to the settings of all the injection parameters that have to be inserted on the machine control panel. This activity was further analyzed by the interview with the operator responsible for it reported below.

1. **Question:** Why on average do you take more than 16 minutes to set all the parameters?

   "Because they are more than 15 parameters to be manually inserted and the control panel response is quite slow"

2. **Question:** How do you know what the parameters are?

   "I have a product injection molding parameters sheet available for every product"

3. **Question:** Do you have to insert these parameters every time there is a change in production?

"Yes, the parameters are not stored in the machine and they have to be inserted manually every time."

4. **Question:** Why are they not stored on the machine computer?

   "Because the machine do not have sufficient memory to store the parameters of every product and even if it had enough memory, it would create confusion in the system being hundreds of products."

5. **Question:** How do you think this problem can be solved?

   "A possible solution would be increasing the machine computer memory and implement on the system the parameters of every product"

The interview with the operator was useful to better understand what the problems he faces performing this activity are. Keeping in mind what expressed by the operator the solution proposed is to standardize the product associated with each machine in order to reduce the range of products associated with the machines.

At the actual state, excluding few exceptions, almost every product can be produced on every machine. The solution proposed is to associate each product with a single machine in order to achieve a number of products associated with each machine that permits to store their process parameters on the computer.

Table 10 reports the results of the analysis performed on the 158 components that are manufactured in the plastic injection unit reported in the Appendix C. It reports the machine types and quantities on the first two columns and on the last two are reported respectively the quantity of products that can be produced only on a type of machine and the quantity of products that can be produced on every machine.

Table 10: Actual machine - product compatibility

Machine Type	Machine quantity	Products Quantity	
		Machine Correlated	Machine Not Correlated
Engel - 200 tons	x1	3	80
Bodini - 165 tons	x1	26	
Engel - 150 tons	x1	7	
Engel - 100 tons	x3	20	
Arburg - 100 tons	x1	12	
Bodini - 100 tons	x2	5	
Engel - 100 tons bi-injection	x1	5	

Source: Elaborated by the author

The countermeasure proposed is then showed in the Table 11. It consists in associating to each machine fixed products and in this way making possible the storage of their parameters on the system.

Table 11: Product compatibility after countermeasure 4 implementation

Machine Type	Machine quantity	Products Number		
		Machine Correlated	Machine Not Correlated	Total
Engel - 200 tons	x1	3	12	15
Bodini - 165 tons	x1	26	-	26
Engel - 150 tons	x1	7	8	15
Engel - 100 tons	x3	20	25	45
Arburg - 100 tons	x1	12	3	15
Bodini - 100 tons	x2	5	25	30
Engel - 100 tons bi-injection	x1	5	7	12

Source: Elaborated by the author

On the one hand, the implementation of the countermeasure proposed has the huge benefit of reducing the parameter adjustments to a value of approximately one minute and thus saving 15 minutes. A further advantage of the countermeasure is that it has as only investments the technician intervention for the storing of data on the machine computer.

On the other hand the major drawback is the larger effort requested for the production planning. This could be a big problem for the implementation of the countermeasure since the association product-machine adds a variable to the planning activity.

Drawbacks apart the implementation of this countermeasure leads to an increase in capacity of:

$$Production\ capacity\ gain\ countermeasure\ 4 =$$

$$= 612\,\frac{setup}{year} \times 15\,\frac{minutes}{setup} \times \frac{1}{60}\,\frac{hour}{minutes} = 153\,\frac{hours}{year}$$

Moreover, it leads to an economical saving computed as:

$$Saving\ Solution\ 4$$

$$= \left(\frac{Nr.setup}{year}\right) \times (hours\ saving\ ) \times (machine\ hourly\ cost)$$

$$- machine\ technician\ intervention$$

$$= 612 \frac{setup}{year} \times 0.25 \frac{hours}{setup} \times 60 \frac{€}{hour} - 250€ = 8930 \frac{€}{year}$$

5.3.2 Countermeasure 5: New clamps implementation

The activities of removing and fixing clamps during the mounting and dismounting of the mold activity, as showed before, account respectively for approximately 7 minutes each.

The clamps actually used are shown in the Figure 49. These have many drawbacks since they are heavy, difficult to handle and have to be fully dismounted at every setup. Moreover, the problems in the handling were highlighted also during the screwing and fixing of the clamp because being heavy it takes time to the operator to center it in the right position.

Figure 49: Actual utilized clamp

Source: Elaborated by the author

The proposed countermeasure consists in substituting the present clamps with more sophisticated ones that do not need to be disassembled from the platen at every setup.

The choice of the new clamp was based on the parameters showed in the Table 12. The only one that can vary slightly between the molds is the clamping eight that is not constant.

Table 12: Clamp parameters requirements

ITEM	CHARACTERISTIC
Machine type	Engel
Bolt size in platen	2 cm
Tapped hole size in platen	16 mm
Clamping height	2-6 cm
How many clamps per machine	8
Reach of the clamp	Not importuned

Source: Elaborated by the author

The clamp type optimal for the actual situation was individuated in the model: Lenzkes Multi Quick 60 (Figure 50).

Figure 50: Clamp Lenzkes Multi Quick 60

Source: Lenzkes website (http://uk.lenzkes.com/multiquick)

The main advantage and goal is to leave the clamps on the machine when the company does the mold changes. This will speed up the change over a lot and no more looking for bolt washers and other parts will be requested. Moreover, the functioning of this tool is simpler, it consists in loosening the ball pressure screw and make the clamping arm slid backwards, thus allowing the mold removal.

Another important factor is that when using the clamps actually present in the company after some time the tapped holes in the platen wear out and either have to be drilled out and re-taped or inserts have to be inserted. Both these actions are time consuming tasks and costly.

The benefits achieved by implementing this countermeasure can be evaluated as the time saved in the assembling and disassembly of the clamps from the platens. The saving was estimated in 3 minutes for the clamp dismounting and 4 minutes for the clamp mounting.

$$Production\ capacity\ gain\ countermeasure\ 5 =$$

$$= 612\frac{setup}{year} \times 7\frac{minutes}{setup} \times \frac{1}{60}\frac{hour}{minutes} = 71\frac{hours}{year}$$

Thus, the maximum economical savings can be calculated as the net difference between the costs incurred and the benefits achieved. The cost of buying the set of clamps were provided by the supplier Lenzkes and is of 181€ for each clamp.

$$Investment\ Solution\ 5$$

$$= Clamp\ unity\ cost \times Nr.clamps\ per\ machine \times Nr.machines$$

$$= 181 \frac{€}{unit} \times 8 \frac{units}{machine} \times 10\ machines = 14480€$$

Considering a 5-year depreciation, the total cost were of 2896€ per year.

$$Saving\ Solution\ 5 = Benefits - Costs$$

$$= (Production\ Capacity\ gain) \times (machine\ hourly\ cost) - Depreciation\ cost =$$

$$= 92 \frac{hours}{year} \times 60 \frac{€}{hour} - 2896€ = 1364 \frac{€}{year}$$

5.3.3 Countermeasure 6: Two operators working in parallel

The distance traveled by the operator together with the time spent walking are two fundamental aspects to be taken into account.

During a standard working day, an operator can perform up to four setups and this is a very energy consuming activity if executed as it is done in the actual state. Fatigue is an aspect that should not be underestimated especially when the operator works in an environment full of risks. Moreover, during the setup the operator handles the molds that have a huge economic value for the company.

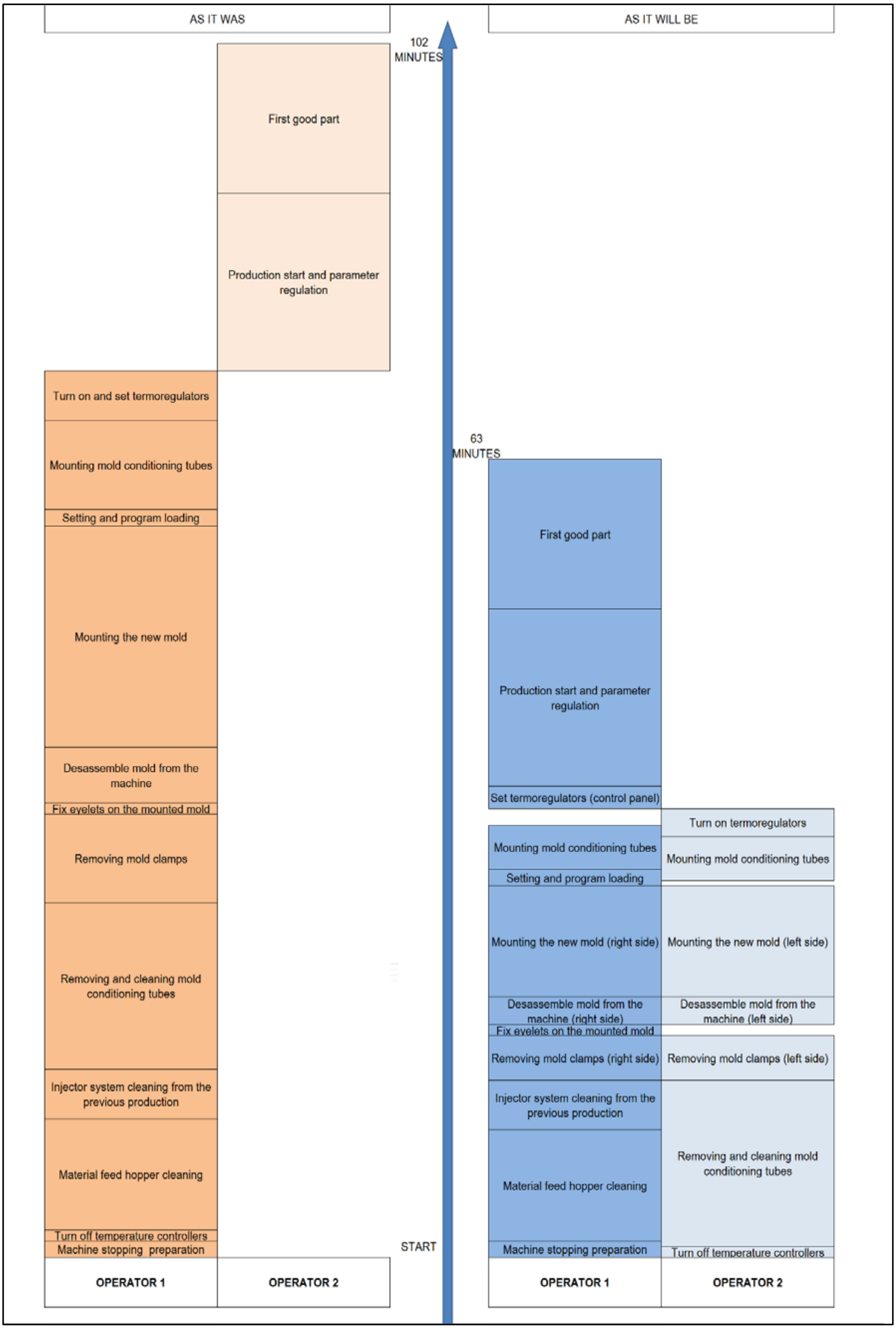
A countermeasure of the problem just described that would reduce both the time spent for a setup and the distance traveled by the operator is the splitting of the tasks between two operators working in parallel and not in series as actually happens.

The big advantage of utilizing two operators is that the number of times the operator goes from one side to the other side of the machine is drastically reduced and more phases of the setup process can be executed in parallel.

The operator multiple activities chart in Figure 51 shows both the “as it was” and the “as it will be” states.

The operations considered were just the internal ones that are those important from the production capacity point of view. Moreover, the aim of this chart is to give the operators a scheme of what are the activities that each of them has to perform.

Figure 51: Operator multiple activities analysis



Source: Elaborated by the author

Full implementation of this improvement proposal brings a theoretical reduction of setup time from 102 minutes to 63 minutes and thus a saving of 39 minutes.

The implementation of this countermeasure can be hampered by the operators' knowledge and competences. The operator 1 is responsible for the mold changeover and does not have the competences for the machine setting and startup, while the operator 2 only has the competence to startup the machine and does not have the ones needed for the setup itself. In order to solve this issue a training course of approximately 30 hours have to be provided to operators with missing competences.

This countermeasure has two main benefits. The first one is the 39 minutes time saving in the setup process itself and the other one is the more flexibility the operators have after the training course, being in this way able to replace the colleagues during their holidays and period of illness. Data needed to compute the economic value of this second benefit was not available to the author and therefore was excluded by the following calculation.

$$Production\ capacity\ gain\ countermeasure\ 6 =$$

$$= 612\frac{setup}{year} \times 39\frac{minutes}{setup} \times \frac{1}{60}\frac{hour}{minutes} = 397\frac{hours}{year}$$

On the other hand, costs include the training course and the salary increase due to operators' competence growth. The first one account for about 1000€ and is a onetime investment, while the salary increase generates an increase in costs for the company of approximately 100€ per month per operator and being five the operators that can deal with the setup the total annual cost is of 6000€.

$$Investment\ countermeasure\ 6$$

$$= Training\ course\ cost + costs\ due\ to\ salary\ increase$$

$$= 1000€ + 100\frac{€}{month} \times 12\ months \times 5\ operators = 7000€$$

$$Saving\ Solution\ 6 = Benefits - Costs$$

$$= (Production\ Capacity\ gain) \times (Machine\ hourly\ cost) - Investment =$$

$$= 397\frac{hours}{year} \times 60\frac{€}{hour} - 7000€ = 16820\frac{€}{year}$$

6 DISCUSSION OF EXPECTED RESULTS

This chapter has as objective the further discussion of the countermeasure proposed in the previous chapter.

A plan of action will be identified for their implementation and the order in which they should be implemented by making a comparison between the proposed countermeasures and their actual impact on the company business.

Then a part will be dedicated to the expected results that can be achieved by implementing every countermeasure proposed.

6.1 IMPLEMENTATION PLANNING OF THE PROPOSED COUNTERMEASURES

The benefits, costs and gains of the six countermeasures proposed in the chapter 5 are reported in the Table 13. Thank to this table a proper comparison can be made directly between the gain in production capacity, the benefits, the costs and the savings of each countermeasure. To be noted that at the time of the end of the internship none of the countermeasures proposed had been implemented yet.

Table 13: Countermeasures (CM) proposed comparison

CM No.	Production capacity gain	Production capacity gain2	Benefit (B)	Cost (C)	Saving	Ratio B/C
[-]	[minutes/ setup]	[hours/ year]	[€/year]	[€/year]	[€/year]	[-]
1	42	428	€ 25,680	€ -	€ 25,680	∞
2	7	71	€ 4,260	€ 3,000	€ 1,260	1.4
3	10	102	€ 6,120	€ 1,700	€ 4,420	3.6
4	15	153	€ 9,180	€ 250	€ 8,930	36.7
5	7	71	€ 4,260	€ 2,896	€ 1,364	1.5
6	39	397	€ 23,820	€ 7,000	€ 16,820	3.4

Source: Elaborated by the author

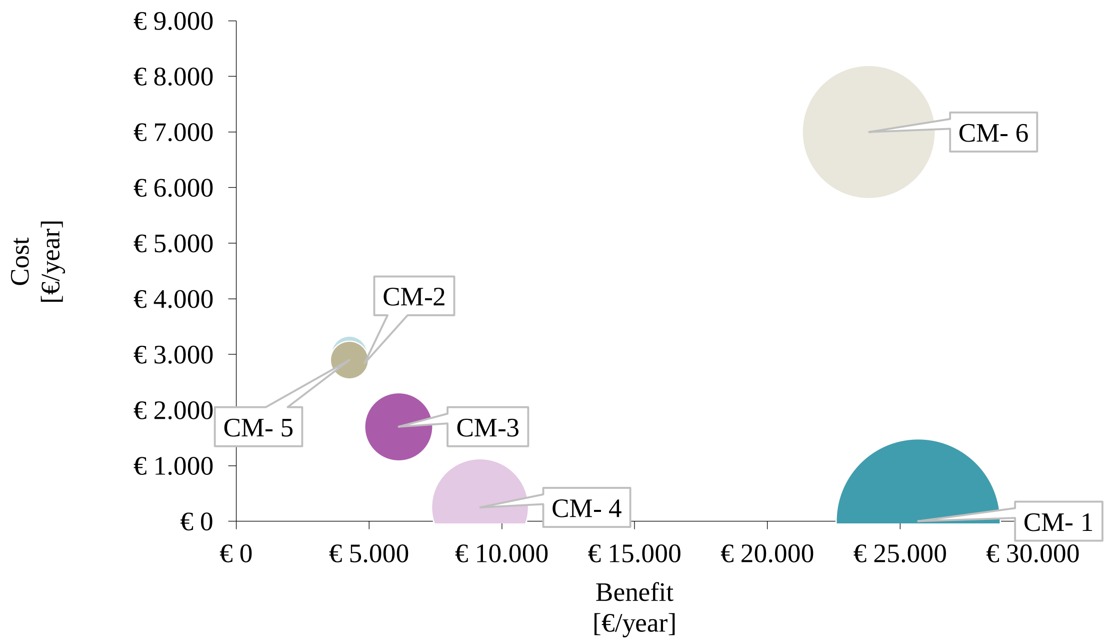
The last column shows the benefits-costs ratio of the countermeasure. This value is useful to evaluate whether a countermeasure is better than another taking into account the investment associated with it and the benefits that it brings. Greater is the B/C ratio, greater the benefits with respect to the costs.

The six countermeasures proposed where then reported on a chart (Figure 52) showing cost, benefit and savings for each of them. The cost and benefit are represented by the chart axis, while the saving is proportional to the bubble dimensions.

It is evident that countermeasure 1 and 6 bring further more benefit and savings with respect to the other four countermeasures, thus they should be implemented first despite the larger investment needed for countermeasure 6.

After the implementation of these two the other should be respectively implemented according to their importance for the company business in the following order: countermeasure 4, countermeasure 3 and 2 together and to conclude countermeasure 6.

Figure 52: Comparison between proposed countermeasures



Source: Elaborated by the author

Once an accurate analysis of the countermeasures was performed, the action plan in the Table 14 for their implementation was created.

The action plan resumes the activities of DO, CHECK and ACT of the PDCA cycle.

For each countermeasure are presented the following data:

- The implementation period needed for the complete application in the plastic production unit

- The period of time needed to have a proper check of the result brought by the countermeasure
- The day in which it is expected the countermeasure validation by comparing the expected results with the actual results brought
- The countermeasure extension period to other production units inside the company and their standardization.

Table 14: Action plan

Action plan		Implementation			Results check	CM validation	CM extension
		start date	Period	end date			
CM 1	Checklist implementation	01/03/2016	14 days	15/03/2016	2 months	16/05/2016	2017
CM 6	Two operators working in parallel	01/03/2016	21 days	22/03/2016	2 months	23/05/2016	2017
CM 4	Adjustment and regulation elimination	23/05/2016	36 days	27/06/2016	5 months	28/11/2016	2017
CM 3	Mold preheating system	27/06/2016	30 days	26/07/2016	3 months	26/10/2016	2017
CM 2	Mold conditioning channels and tubes emptying	27/06/2016	30 days	26/07/2016	4 months	25/11/2016	2017
CM 5	New clamps implementation	01/09/2016	30 days	03/10/2016	2 months	05/12/2016	2017

CM= countermeasure

Source: Elaborated by the author

The aim of the action plan proposed was to give the company a planning of the activities to be performed within the 2016 in order to implement every solution analyzed and still having enough time for their check and validation.

6.2 EXPECTED RESULTS

The present chapter offers an overview of the results expected by a full adoption of what proposed in this work until now.

Figure 53 exhibits the future results that can be achieved with the countermeasures presented in chapter 5 divided according to the three steps proposed by Shingo (1985).

For each phase of the setup process is showed the duration and the classification that can be either internal or external. Moreover, after the step 3 implementation there are some activities that are performed by both the operators that cut in half the time spent for them.

Figure 53: Single Minute Exchange of Die expected results

	Setup Process Phase	Step 1 Op.1	Step 1 Op.2	Step 2 Op.1	Step 2 Op.2	Step 3 Op.1	Step 3 Op.2	Duration variation [%]
EXTERNAL	Mark stop in the production sheet	1,6						-100%
	Problems with machine safety sensors	10,8						-100%
	Seek the forklift	4,3						-100%
	Get the new mold	5,7						-100%
	Seek the cart with the tubes	2,1						-100%
	Sheet molding printing at the PC	1,8						-100%
INTERNAL	Machine stopping and setup preparation	0,8		0,8		0,8		0%
	Turn off temperature controllers	0,6		0,6			0,6	0%
	Material feed hopper cleaning	10,3		10,3		10,3		0%
	Injector system cleaning	4,3		4,3		4,3		0%
	Removing mold conditioning tubes	6,9		6,9			6,9	0%
	Removing mold clamps	7,6		7,6		2,3	2,3	-70%
	Fix screw eyelets on the mounted mold	1,2		1,2		1,2		0%
	Desassemble mold from the machine	4,5		4,5		2,3	2,3	-50%
	Mounting the new mold	15,2		15,2		6,0	6,0	-61%
	Machine setting and program loading	1,1		1,1		1,1		0%
	Mounting mold conditioning tubes	7,4		7,4		3,7	3,7	-50%
	Turn on and set termoregulator	6,4		6,4		3,2	3,2	-50%
	Production start and parameter regulation		16,4		16,4	1,4		-91%
	First good part		13,7		3,7	3,7		-73%
EXT	Mark stop on the production sheet	1,3						-100%
	10 minutes rest pause	10,0						-100%
	Cleaning mold conditioning tubes	7,0						-100%
	Put the forklift back in its position	1,9						-100%
	Cleaning the machine	2,3						-100%

Source: Elaborated by the author

The last column of Figure 53 shows the final variation in time expected for each phase of the setup having as reference just the internal activities point of view and thus the added value activities. For this reason all the activities identified as external have a 100% gain. It is to be highlighted that the external activities were not completely eliminated but just considered as not part of the set of actions that actually add value to the company business.

The overall setup time reduction expected can thus be computed as:

$$Setup\ time\ reduction = Setup\ time\ before\ SMED - Setup\ time\ after\ SMED$$

$$= 145\ minutes - 40\ minutes = 105\ minutes$$

Also, another important improvement expected is the reduction of the distance traveled by the operator during the setup. In order to show this improvement a new spaghetti chart (Figure 54) was developed estimating the new distances and paths followed

The total distance traveled by the operators was decreased significantly. The operator 1 travels a distance of about 50 meters while the second operator travels 80 meters. The total distance was then decreased of 91%, from 1572 meters to 130 meters.

Figure 54: Spaghetti chart expected after solutions implementation

Source: Elaborated by the author

7 CONCLUSIONS

This work has explored the application of a typical WCM improvement project from the problem identification, passing through the application of specific tools to analyze the company situation and the utilization of problem solving techniques to find the countermeasures that best fit the company strategy and business.

First, the plastic injection unit was identified as bottleneck thanks to the machine utilization index, the Cost Deployment Matrix and the expected demand to be satisfied in 2016 and was analyzed to find what was between the six big losses the most critical one inside the department.

Next, the SMED method was used to analyze the current changeover process and, once individuated the longest activities, actions were identified to reduce them and to propose a new changeover scheme.

It was found that the historical average changeover time in the plastic injection unit was 110 minutes with an average peak time on a machine of 145 minutes; 29% of which was done externally. The machine analyzed was then this last one. At this point the aim was to define a new changeover method to maximize the operators time and minimize the machine downtime by utilizing the SMED techniques and tools such as Pareto chart, Spaghetti chart, Ishikawa diagram, 5 Whys and 5W+1H.

As a result of the study, 12 possible countermeasures to the previously highlighted problems were identified and the 6 of them that bring the highest benefit were chosen to be implemented. The 6 countermeasures proposed as the first that have to be implemented have a long reach and regard all the aspects of the setup process. Some of them, such as the implementation of a checklist and operators working in parallel, regard the method followed by the operators that was not present and others take into account the tools used by the operators, such as the implementation of new clamps and of a mold preheating system.

The benefits brought by the adoption of the 6 countermeasures proposed was summarized in Table 13 and, as reported in Chapter 6.2, the expected reduction in setup time is of 105 minutes each for the machine considered, yielding 72% in time saving. This is clearly a very large saving and if these methods are implemented then the company will achieve significant results, increasing the available production capacity and reducing the costs.

To conclude the study, an action plan (Table 14) was created in order to have a clear idea of what have to be implemented and when, considering the boundary conditions that limit the company actions such as the availability of resources to make the investments required. In the action plan were also considered the implementation period required, the period needed to check and validate the countermeasure and when it should be extended to the other production units.

The next steps for the company for next studies, after the implementation of the six proposed and analyzed countermeasures, are to further analyze the other six countermeasures that were just listed and not explored deeply within this study in Chapter 5, implementing them and further reducing the setup time in order to complete the SMED application reaching a single digit setup time as stated by Shingo (1985). Moreover, the company, after having completed the SMED application, should extend and standardize the changeover in every plant and production unit and then identify the new bottleneck by repeating the analysis performed in Chapter 4.1.2 and 4.1.3 with updated data.

As a conclusion, the WCM methodology application should not be seen as an increase in workload as it actually happens inside Giobert but as a continuous improvement of the productive processes, being always present opportunities for optimization.

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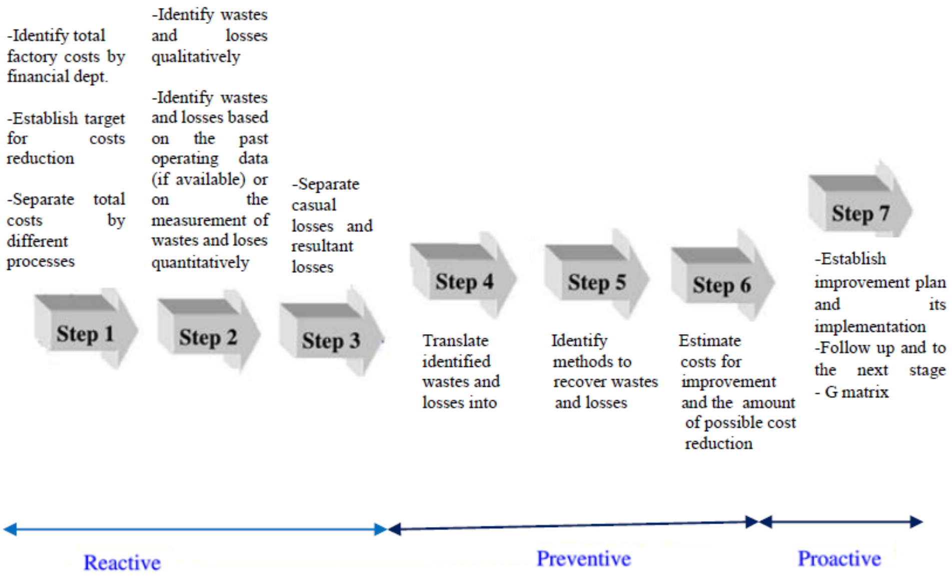
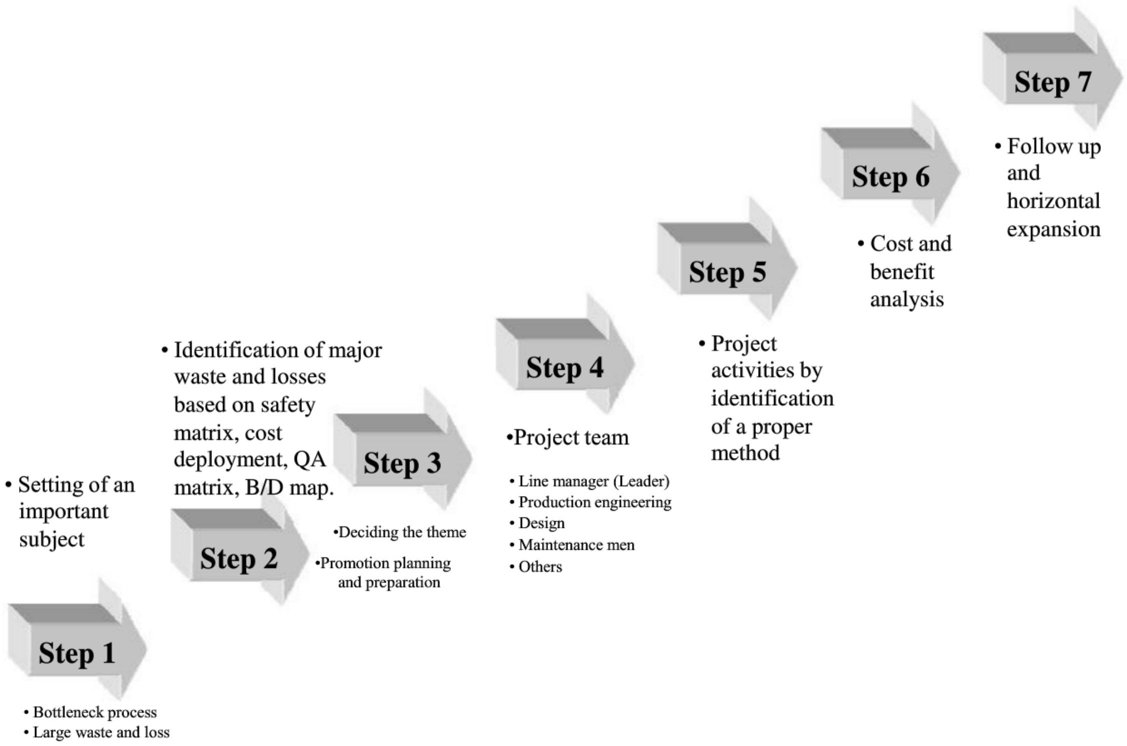
APPENDIX A: SEVEN STEPS OF THE TECHNICAL PILLARS

A1: THE SEVEN STEPS OF SAFETY

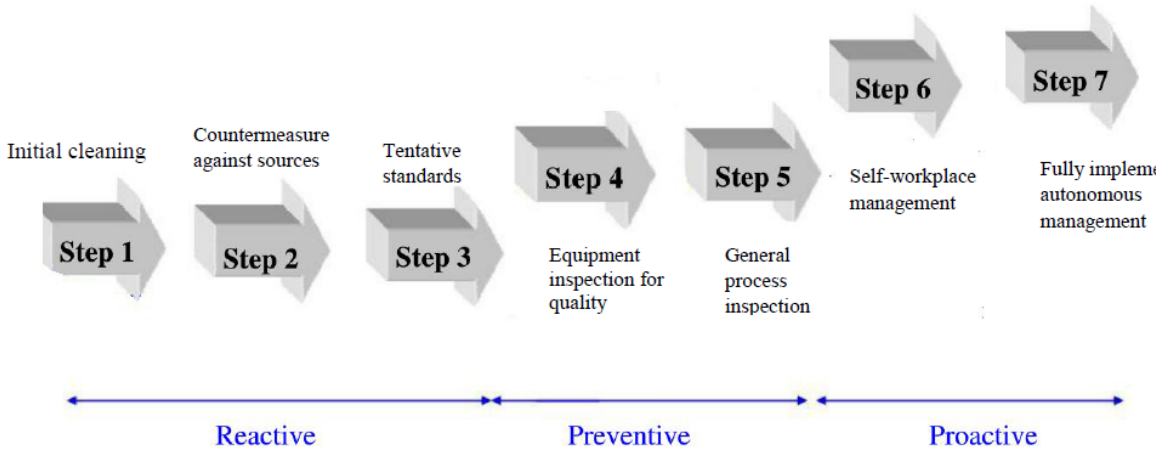
A 2: THE SEVEN STEPS OF COST DEPLOYMENT



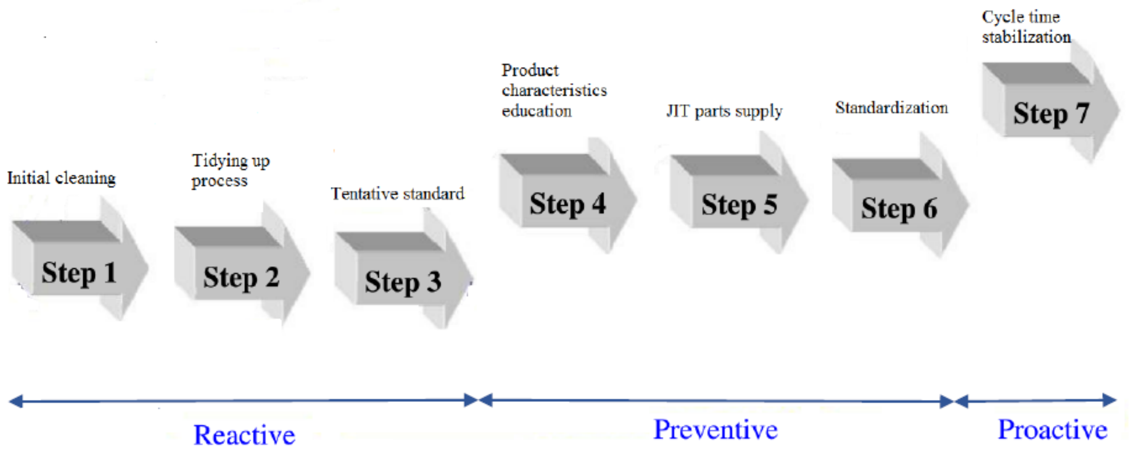
A 3: THE SEVEN STEPS OF FOCUSED IMPROVEMENT



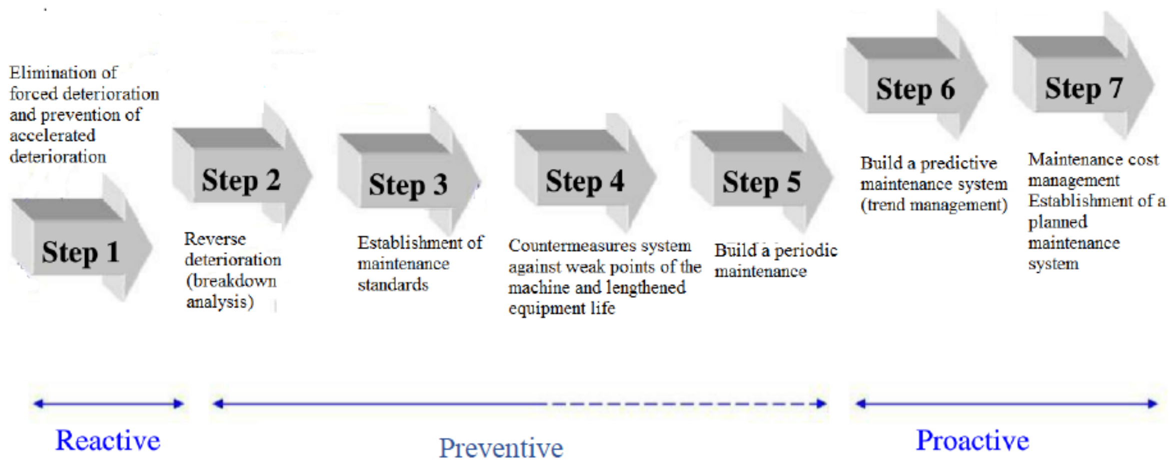
A 4: THE SEVEN STEPS OF AUTONOMOUS MAINTENANCE



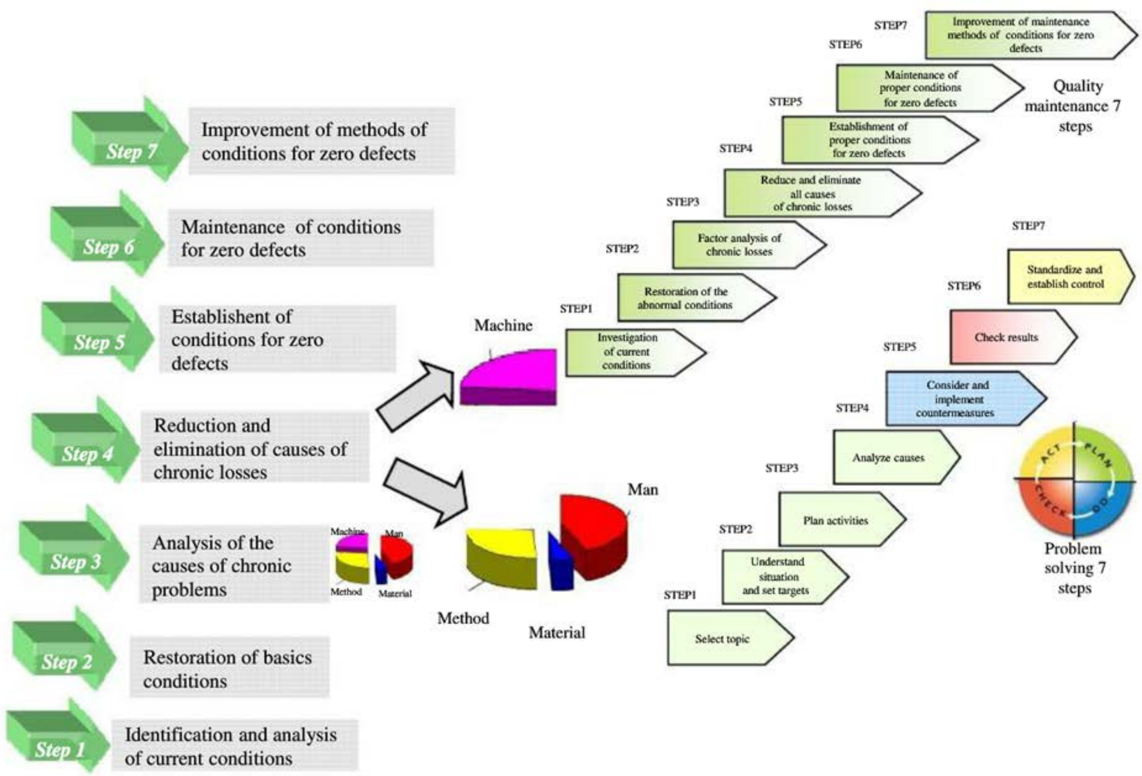
A 5: The Seven Steps of Workplace Organization



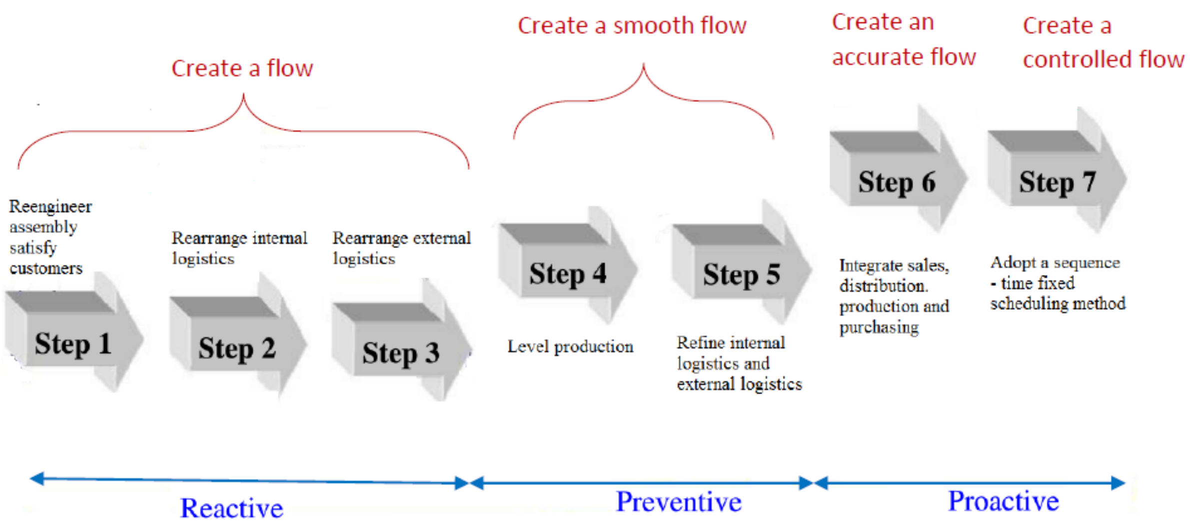
A 6: THE SEVEN STEPS OF PROFESSIONAL MAINTENANCE



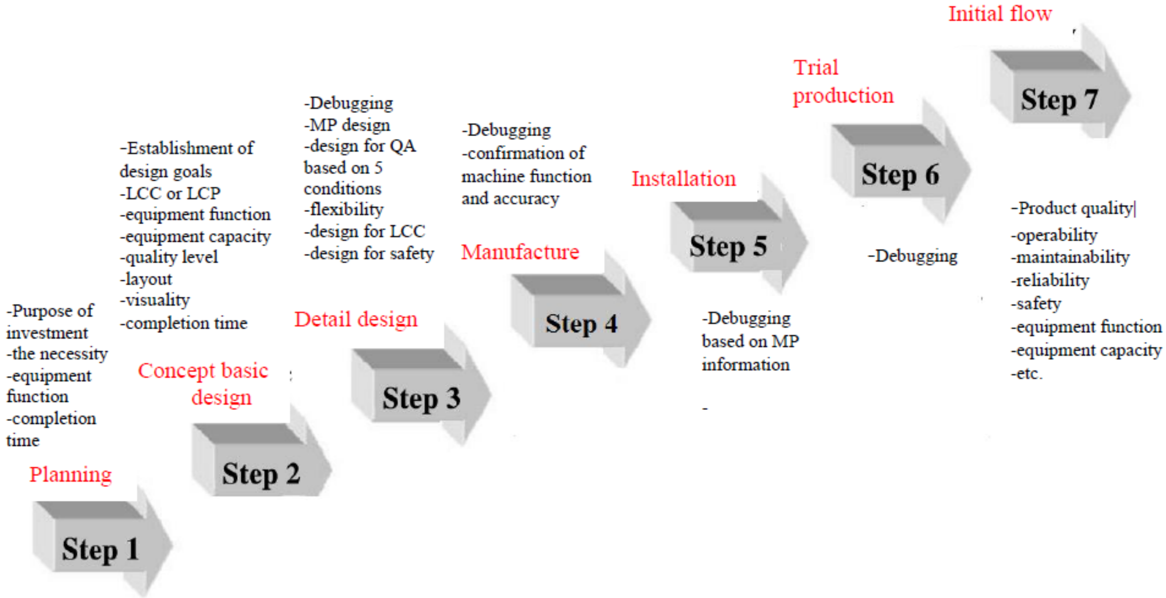
A 7: The Seven Steps of Quality Control



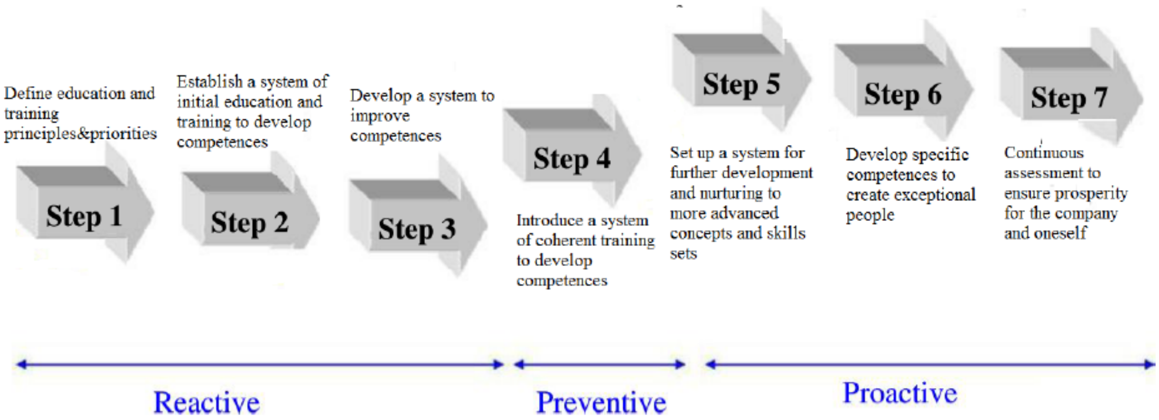
A 8: The seven steps of Logistics/Customer Service



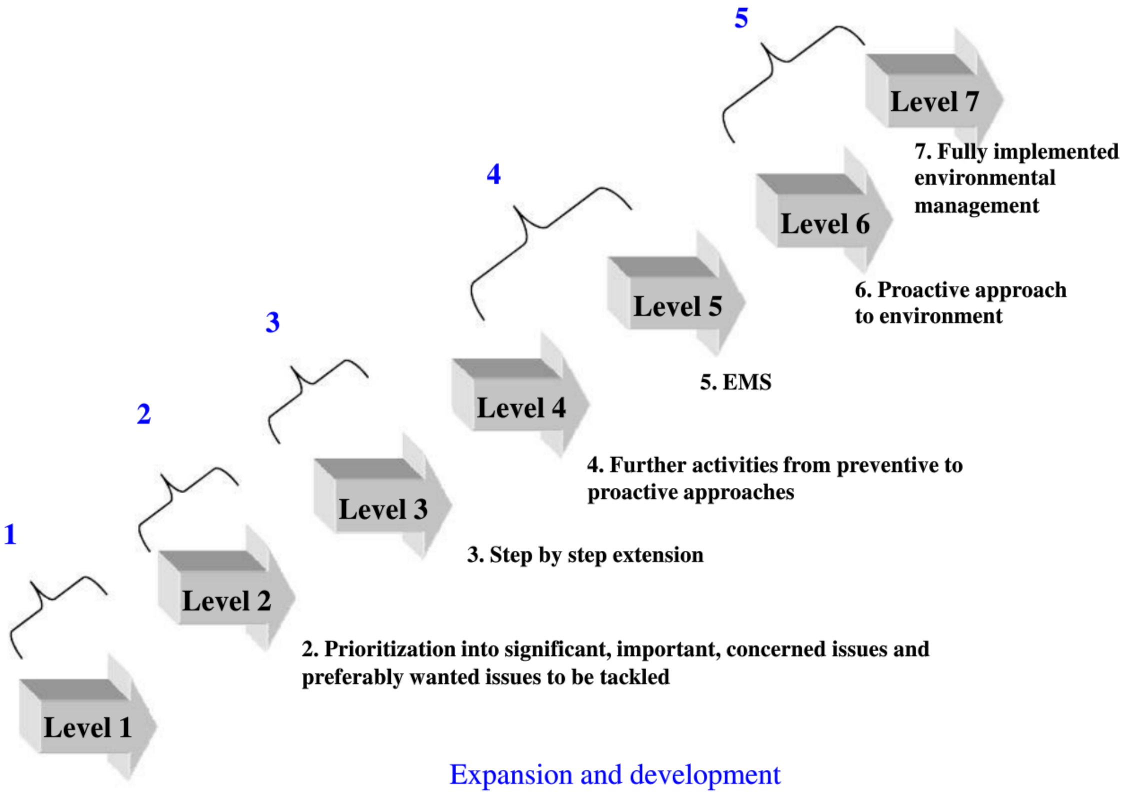
A 9: THE SEVEN STEPS OF EARLY EQUIPMENT MANAGEMENT



A 10: THE SEVEN STEPS OF PEOPLE DEVELOPMENT

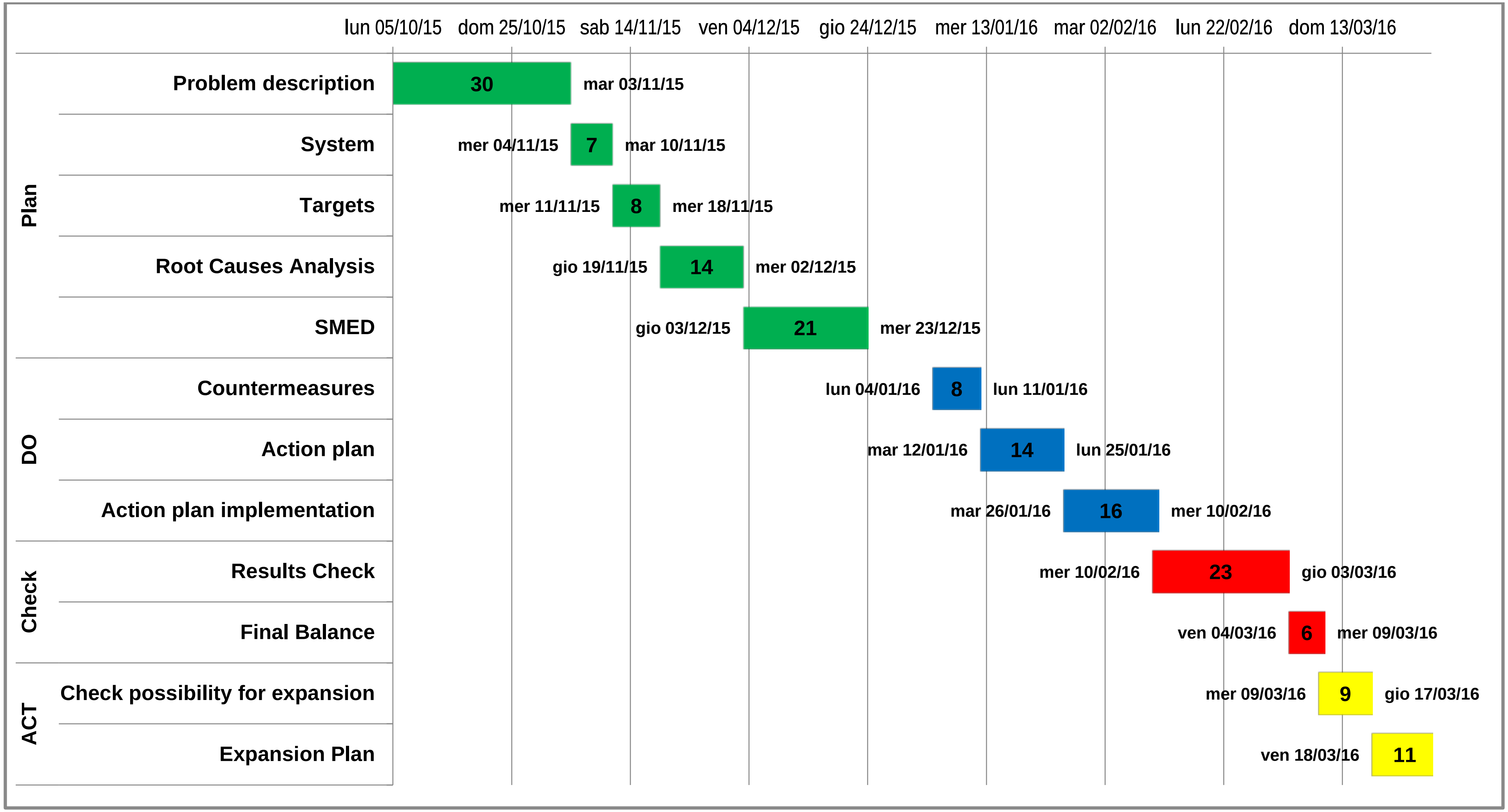


A 11: THE seven STEPS OF ENVIRONMENT



Source: YAMASHINA WCM presentation

APPENDIX B: INITIAL PROJECT PLAN



APPENDIX C: MACHINE – PRODUCT COMPATIBILITY

Item	Bodini - 165t	Engel - 100t	Engel - 200t	Engel - 150t	Engel - 100t2	Bodini - 100t	Bodini - 100t2	Engel - 100t3	Arburg - 100t	Engel - 100t bi-injection
P. 01	x									
P. 02									x	
P. 03					x					
P. 04					x					
P. 05					x					
P. 06							x			
P. 07						x				
P. 08					x					
P. 09					x					
P. 10	x						x			
P. 11	x						x			
P. 12			x			x	x			
P. 13						x	x			
P. 14					x					
P. 15						x				
P. 16					x					
P. 17									x	
P. 18				x						
P. 19						x				
P. 20					x	x		x		
P. 21									x	
P. 22	x				x					
P. 23			x							
P. 24	x		x							
P. 25					x	x				
P. 26					x	x				
P. 27		x								
P. 28		x								
P. 29		x			x					
P. 30		x			x					
P. 31			x							
P. 32								x		
P. 33								x		
P. 34								x		
P. 35								x		
P. 36	x				x	x		x		
P. 37	x				x	x		x		
P. 38		x			x	x	x			
P. 39					x	x	x	x		
P. 40						x		x		
P. 41						x		x		
P. 42			x							
P. 43		x								
P. 44									x	
P. 45	x		x							
P. 46	x							x		
P. 47					x		x			
P. 48	x		x							
P. 49	x							x		
P. 50					x	x		x		

P. 51	x					x	x			
P. 52								x	x	
P. 53	x		x	x						
P. 54	x			x		x				
P. 55					x	x	x	x		
P. 56					x	x	x	x		
P. 57					x	x				
P. 58	x		x		x			x	x	
P. 59				x	x					
P. 60					x	x	x			
P. 61				x	x					
P. 62			x	x	x			x		
P. 63	x	x								
P. 64			x	x	x			x		
P. 65	x	x								
P. 66				x						
P. 67				x					x	
P. 68					x	x	x	x		
P. 69		x						x		
P. 70		x			x		x			
P. 71	x	x		x				x		
P. 72	x					x				
P. 73					x	x				
P. 74					x	x				
P. 75					x					
P. 76		x						x	x	
P. 77										
P. 78										
P. 79										
P. 80					x					
P. 81					x	x				
P. 82					x					
P. 83					x	x				
P. 84					x					
P. 85			x		x	x				
P. 86				x				x		
P. 87					x					
P. 88							x			
P. 89							x			
P. 90						x				
P. 91					x					
P. 92					x					
P. 93					x					
P. 94					x				x	
P. 95					x					
P. 96					x		x			
P. 97				x	x					
P. 98							x			
P. 99										x
P. 100										x
P. 101		x								
P. 102								x	x	
P. 103								x		
P. 104								x		
P. 105								x		
P. 106								x		
P. 107								x		
P. 108								x		
P. 109									x	
P. 110										x
P. 111					x		x			
P. 112						x				
P. 113					x				x	
P. 114								x		
P. 115		x		x				x		
P. 116									x	
P. 117									x	
P. 118	x							x		
P. 119	x							x		
P. 120			x		x			x		
P. 121		x				x	x		x	
P. 122		x	x		x			x		
P. 123									x	
P. 124									x	

P. 125									x	
P. 126	x	x	x						x	
P. 127								x	x	
P. 128								x	x	
P. 129								x	x	
P. 130					x	x	x		x	
P. 131	x									
P. 132	x									
P. 133	x	x	x						x	
P. 134								x	x	
P. 135								x		
P. 136								x		
P. 137								x		
P. 138								x		
P. 139								x		
P. 140								x		
P. 141		x							x	
P. 142										
P. 143		x							x	
P. 144										x
P. 145		x							x	
P. 146									x	
P. 147									x	
P. 148								x		
P. 149	x									
P. 150				x						
P. 151				x						
P. 152				x						
P. 153				x						
P. 154				x						
P. 155		x	x					x	x	
P. 156								x		
P. 157								x		
P. 158								x	x	