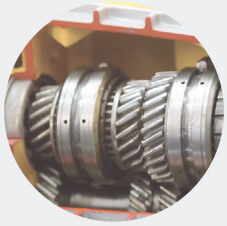
INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO

MESTRADO EM ENGENHARIA MECÂNICA



ANALYSIS AND OPTIMIZATION OF THE PRODUCTION PROCESS

BRUNO MIGUEL VIEIRA MAIA

dezembro de 2018

POLITÉCNICO DO PORTO

Instituto Superior de Engenharia do Porto

ANALYSIS AND IMPROVEMENT OF THE INJECTION MOLDING PRODUCTION PROCESS AND RELATED TASKS

Bruno Miguel Vieira Maia

2018

ISEP – School of Engineering, Polytechnic of Porto
Mechanic Department

POLITÉCNICO
DO PORTO

POLITÉCNICO
DO PORTO

ANALYSIS AND IMPROVEMENT OF THE INJECTION MOLDING PRODUCTION PROCESS AND RELATED TASKS

Bruno Miguel Vieira Maia
1130581

Dissertation presented to ISEP – School of Engineering to fulfill the requirements necessary to obtain a Master's degree in Mechanical Engineering, carried out under the guidance of Doctor Francisco José Gomes da Silva, Adjunct Professor at ISEP – School of Engineering, Polytechnic of Porto.

2018

ISEP – School of Engineering, Polytechnic of Porto
Mechanical Engineering Department

POLITÉCNICO
DO PORTO

POLITÉCNICO
DO PORTO

JURY

President
Luís Carlos Ramos Nunes Pinto Ferreira, PhD
Adjunct Professo, Instituto Superior de Engenharia do Porto
Supervisor
Francisco José Gomes da Silva, PhD
Adjunct Professor, Instituto Superior de Engenharia do Porto
Examiner
Radu Godina, PhD
Researcher, Universidade da Beira Interior

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Prof. Francisco Silva, for providing me all the necessary guidance for this dissertation, for all the understanding, support, and openness.

I would like to thank especially to Pedro Miranda for believing in me and giving me this opportunity to start my professional life in such a renowned company.

I would like to thank as well to all the people in engineering department, especially to Henrique Silva, Pedro Miranda and Agnieszka Rhiza for their friendship, help and support.

Also, I would like to thank to all my friends for their friendship throughout all these university years.

Finally, I would like to express my greatest thanks for my family, especially for my MOTHER and my girlfriend, who always believed in me even when I did not, for the continuous encouragement, support, attention and patience. Without you both I believe I would not be writing this right now, from the bottom of my heart THANK YOU.

KEYWORDS

Production process, Analysis, Workstation control, Lean tools. Improvement, 5S, VSM. PDCA.

ABSTRACT

This dissertation describes an approach to the improvement of the production process of an automobile plastic part. The improvement of this productive process intends to increase labor utilization, reducing all related costs and activities along the process such as semi-product's stocking, as well as reduce the logistic flows and the existing components' assembly workstation of the analyzed part.

The methodology used in this project focus on the application of tools to analyze and improve productive processes, such as the process diagram, the spaghetti diagram, PDCA, tasks' time registration and VSM (Value Stream Mapping).

The use of the process and spaghetti diagrams and the time registration tools allowed clearer information about the current status of the productive process. The analysis of the current status reveals that there is a great amount of waste in both workstations - injection and assembly - on what regards workers' time occupation.

The application of PDCA with its actions' plan allows the change to happen successfully.

The intention of the project is to show that the current status can always be improved using the correct tools to analyze and propose changes which will in the short term bring savings to the company.

The second part of the dissertation describes the creation and implementation of a second assembly line, which has the same way of working as the first one, but with improvements to overcome the failures found in the first stage. The reason for the creation of this second assembly line is the fact that the company is not able to respond to the increased demand for the following months / years with only one assembly line.

PALAVRAS CHAVE

Processo produtivo, Análise, Controlo de posto de trabalho, Ferramentas Lean, Melhoria, 5S, VSM. PDCA.

RESUMO

A dissertação descreve o levantamento e melhoria do processo de fabrico de uma peça plástica para um automóvel. A melhoria deste processo produtivo tem em vista a rentabilização de recursos humanos, a redução de custos associados e a redução de atividades ao longo do processo, tais como armazenamento de produto semiacabado, a redução de fluxos logísticos e a análise do posto de montagem.

A metodologia utilizada neste projeto centra-se na aplicação de ferramentas que permitem a análise e melhoria de processos produtivos, tais como o diagrama de processo, o diagrama spaghetti, o PDCA, a cronometragem dos tempos por tarefa e o VSM (*Value Stream Mapping*) da peça em estudo.

O diagrama de processo, o diagrama de spaghetti e a cronometragem dos tempos por tarefas mostraram o estado atual do processo produtivo. Da análise do estado actual, verifica-se que existe muito desperdício de mão-de-obra nas duas estações de trabalho: injeção e montagem.

A aplicação do ciclo PDCA, na base da qual está a elaboração de um plano de ações, tornará esta mudança possível e bem-sucedida.

A intenção deste projeto é demonstrar que o estado atual pode sempre ser melhorado se se usarem as ferramentas corretas para análise e proposta de melhorias que trarão ganhos à empresa a curto prazo.

A segunda parte desta dissertação descreve a criação e implementação de uma segunda linha de montagem com o mesmo método de trabalho, no entanto, com melhorias para combater e eliminar as falhas encontradas na primeira linha de montagem. A razão da criação desta segunda linha de montagem é o facto de a empresa não ser capaz de responder as ordens de encomenda dos próximos meses/anos com apenas uma linha de montagem.

LIST OF SYMBOLS AND ABBREVIATIONS

BOM - Bill of Material
CAD – Computer aided design
CT - Cycle time
EOP - End of Production
INJ - Injection;
JIT – Just in time
Li - links – left side
Re – Rechts – right side
MAQ - Machines
N.º - Number
NOK - Not OK
NT - Normal Time
Op - Operator
PDCA - Plan, Do, Check, Act
I-code - Product semi-finished
F-code - Finished Product
SOP - Start of Production;
VSM – Value stream mapping
WIP – work in progress
TPS - Toyota Production System
OEE - Overall Equipment Effectiveness
MOD -

FIGURES INDEX

TABLES INDEX

INDEX

1 - INTRODUCTION

1 INTRODUCTION

1.1 Contextualization

The increasing needs of the world population have been intensifying the plastics consumption in various sectors of the industry - automotive, aeronautical, and electronic, etc. This demand has raised the level of rising of industry standards, leading to the development of manufacturing processes, requiring more speed in systems production and delivery time, with competitive final costs.

Due to its potential, injection molding has become a very important manufacturing process with great prominence in processing components of polymeric materials, which are increasingly used due to its characteristics such as low weight, flexibility, low electrical/thermal conductivity, high impact resistance, low melting point and easy coloring.

The development of the molding process led to the development of plastics, improving their characteristics, properties and capabilities of forming and molding. This development also led to the emergence of new materials (e.g. biodegradable polymers). The injection moulding process can process thermoplastic, thermosetting, rubber and silicone. This process allows the production of a wide range of parts, varying in size, complexity and application, with dimensional accuracy.

However, the price of the plastic parts tends to decrease and the plastic molding industry needs to become more and more competitive, removing wastes of time in its cycle time and corresponding logistic processes. Thus, Lean tools can assume a key role in the process improvement, leading to an increased competitiveness.

1.2 Main goals

The main objective of this dissertation is to analyse and improve the production processes of plastic parts in the shop floor, this includes all the processes since the company receives the material until it delivers the F-codes (finished products) to the customer. The focus of this dissertation is the injection process and the assembly line of a plastic part for VW Tiguan, called *Einstiegsleisten*, which can be seen in Figure 1.

Figure 1 - *Einstiegsleisten* assembled in the car

1.3 Methodology used

The methodology used in this work was the "action-research" methodology.

1.3.1 Collection of information

A literary research was crucial for this project, giving the theoretical base needed to solve the identified problems. The result of reading books and scientific articles was reminding of the several tools, like VSM (value stream mapping), PDCA (plan, do, check, act), TPS (total production system), which were used to carry out the survey of the current state of a process and to suggest the improvement of productive processes and services. All information needed was given to me by the company and by supervisor.

1.3.2 Work in loco

After getting the knowledge from the books, manuals, scientific articles and some working experience, the analysis and study of the process of *Einstiegsleisten* from VW Tiguan was started. Starting with the analysis of the injection process, the study was followed by the analysis of the assembly line. In the analysis of the process, it was collected information regarding the cycle-time (CT), the time available, the time used by operators to perform the task, all the time wastes and material wastes, all movements.

1.3.3 Analysis of results

After collecting all the data and go through it over and over, a brainstorm was started to find the best solutions. By analysing the data, it was possible to point out some improvements that will help the company to reach the best solution possible.

1.3.4 Implementation

After all calculations have been reviewed, it was time to implement the best solution.

1.4 Thesis´s structure

The thesis is divided into five chapters:

- Introduction – the objectives, justification and organization of this dissertation are presented in this chapter;
- Company overview – this chapter includes the company history, the connection between both divisions, the international company position and a more detailed explanation about the SPP, Simoldes Plasticos Polska, place of the internship;
- Bibliographic work – this chapter will provide information about the theoretical framework used in this thesis. Different concepts from well-established theories as well as more recent studies will be described and explored;
- Thesis development – this chapter aims to analyse the manufacturing processes of VW Tiguan` *Einstiegsleisten*. Besides the characterization of the current production situation, other productive solutions are proposed and analysed;
- Conclusions – this chapter will present a reflection about the advantages and the savings of this thesis for the company.

2 - Company overview

2 Company overview

2.1 Simoldes Group

Simoldes was founded in 1959. It started as a small plant located in Oliveira de Azeméis, in the north of Portugal, and it remains totally owned by a Portuguese family. This company supplies plastic injection molds and manufactures plastic components, mainly for the automobile industry, which represents 90% of its revenues. Current profits are in the order of 650 million euros with more than 5,000 employees employed by the firm. Currently Simoldes is the 8th world and the 3rd European molds producer.

From 1959 till the 1980´s, Simoldes only produced molds for injection companies. In 1981, the group decided to start investing in plastic injection plants. The objective was to produce the tools follow by producing the parts all inside the group.

The group is divided into two big divisions: Simoldes Tool Division and Simoldes Plastic division. At present, the group has manufacturing plants in Portugal, Brazil, France and Poland. Portuguese market only accounts for a symbolic portion of the revenues. Therefore, their focus is in international markets. This group has a strong recognition in the automobile industry with brands like Porsche, Toyota, Citroen, Peugeot, Volkswagen, and Skoda listed among its clients.

2.1.1 Simoldes Tool Division

This division of the group is responsible for the manufacturing of injection molds for the plastic components. These molds are a complex set of parts. Their function is to allow the injection of thermoplastic polymers into the mold, where it cools down and hardens in the form of the mold´s cavity. This division is specialized in the production of molds for large plastic components and it exports to more than 30 countries. Simoldes is a reference in the molds industry in Europe and is the leading group in Europe.

ACS Advanced Customer Service

In the most important markets, Simoldes Tool division has created local offices where advanced services are available to their major clients. Technicians and engineers mostly compose these departments. The main objective is to provide commercial and technical support to their customers. After sale services, such as modifications, repairs and maintenance are rapidly provided after the mold arrives at the client.

2.1.2 Simoldes Plastic Division

Simoldes Plastic division is a group of 8 companies, with projects to open 2 more plants, another one in Poland and one in Morocco. The mainstream of revenues comes from this division. These companies are responsible for the injection of the plastic into the mold, producing the final components that are sent to assemblers.

There are a department responsible for the development of the final component, using CAD and special programs. Having more than 30 years of expertise, they are able to develop products that make the mold making process easier. These specifications of the final component are then used by the tool division to create the mold required. This department is capable of detecting problems and potential efficiencies that are going to be explored in the mold-making process. This fact creates one of the major sources of competitive advantages of Simoldes as a group. Companies in Simoldes Tool Division produce 90% of the molds used by this plastic division.

CSC - Customer Service Center

This department is also distributed across different strategic locations. The goal is to provide assistance to Simoldes Plastic division main customers, namely auto manufacturers (Figure 2). Engineers and technicians constitute these offices where product development and after sales assistance are provided. These special departments work as a complement to the manufacturing facilities of Simoldes Plastics.

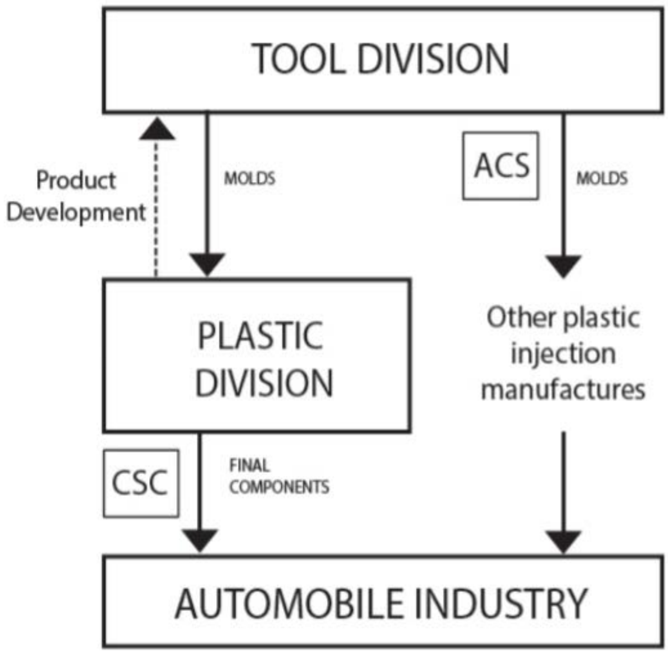


Figure 2 - Connections between both divisions

2.2 Linkages between its two key divisions

The differentiation from their main competitors comes from the integration of mold production and the injection of the plastic within the same group. Usually, mold-making companies are small and specialized, with a small number of clients. On the other hand, plastic injection companies have a larger number of clients. And as many multinational companies, Simoldes try to locate their plants closed to customers.

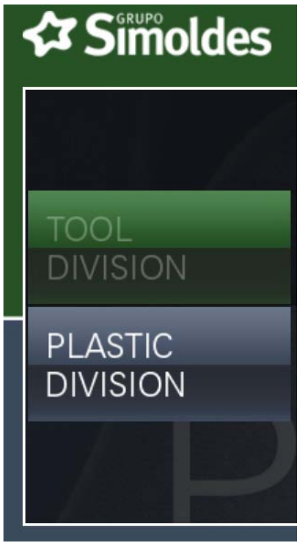


Figure 3 - Simoldes Group

Simoldes group, is now a supplier of large companies in the automotive world, most notably among them those of Audi, Citroen, VW, BMW, Seat, and many others

The integration between tool division and plastic division in Simoldes group brings several advantages that will make the difference against its competitors. With this level of integration, Simoldes can produce plastic parts after the production of the mold. All the process of reaching the final plastic product is much faster when compared with the normal process. The normal process consists in the production of the mold in one company, then moving it to a plastic injection company and finally manufacture of the final component. Having these two divisions inside the same group, it gives to Simoldes a faster response and immediate assistance if any adjustment is required in the mold. Another advantage is that Simoldes can observe directly their own molds working in production. This fact permits them to see and study the roots of problems and deformities in the final plastic part. Most of these problems in the final product occur due to malfunctioning´s of the mold, and the characteristics of the plastic material used. Having teams from plastic and tool division that cooperate together lead to an integration that results in learning economies that are crucial for all the process. Because of this interaction, Simoldes is able to conceive molds with a superior quality, which results in efficiencies in the injection and higher final components quality

2.3 The internationalization process of the Group

In comparison to Portuguese companies in the auto component sector, Simoldes degree of internationalization is very high. A higher percentage of revenues come from international markets. So is necessary a global presence in order to continually raise their sales. Currently, the two divisions have manufacturing facilities in Poland, Brazil, Spain, Czech Republic, France. Concerning the costumer's service, they are present in many other countries.

Usually, when this group decides to enter in a new market they consider several factors. The most important element is to be close to their main customers. This fact decreases the transportation costs and speeds the supply chain. By using the just in time (JIT) practices applied in the automobile industry, companies are expecting to receive components in a way that allows them to hold the minimum inventory possible.

Another important fact is the amount of taxes charges to import goods in a given country. Simoldes was obliged to build a manufacturing plant in Brazil because of the high taxes applied to the imported products.

Another very important fact is the availability of a skilled workforce the local of the facilities, because of the complexity of the products manufactured, mainly in the Tool division. It is essential to have skilled employees with experience and academic training. Due to these factors, countries with low-income are not the natural target in this internationalization process.

Simoldes prefers to enter a market by starting from scratch. Normally, they prefer to build their own manufacturing plants instead of purchasing existing companies. They believe that one of their main sources of competitive advantage is their manufacturing processes and the homogeneous of their plants all over the world.

Simoldes plans to continue their internationalization process. Morocco and Poland (second plant) should be the next steps. However, they are dependent on their clients to open new facilities in these countries.

Regardless of "start from scratch approach", when Simoldes is not able to build new facilities in new countries, has an alternative form of pursuing its international goals: by technical licensing. They have 2 different licensing types. In one of them, they develop the project, being responsible for the installation of the manufacturing process in a given company. Simoldes takes a fee for this service not being accountable for the final manufactured product. The second type, it is a similar process, yet, Simoldes receive a royalty for each product produced by that company. The difference between these 2 types of licensing is that in the second type Simoldes has responsibility for the product and the manufacturing process.

2.4 SPP – Simoldes Plásticos Polska

SPP is the plant where I realized my thesis and where I'm currently working. This is one of the most recent plants from Simoldes Plastics division, built in 2003, currently with over 35 injection machines (from 200 ton until 2000 ton), over 300 tools and over 300 employees. This plant is growing in such an incredible speed that there is planned a construction of the second plant in Poland to face the high demand for the new projects. The mission of the company is to be the preferred choice of their customers, employees and suppliers, contributing to sustainable growth and satisfying their shareholders.

2.5 Simoldes products

Simoldes produces a great variety of products, as can be seen in Figure 4 and Figure 5.

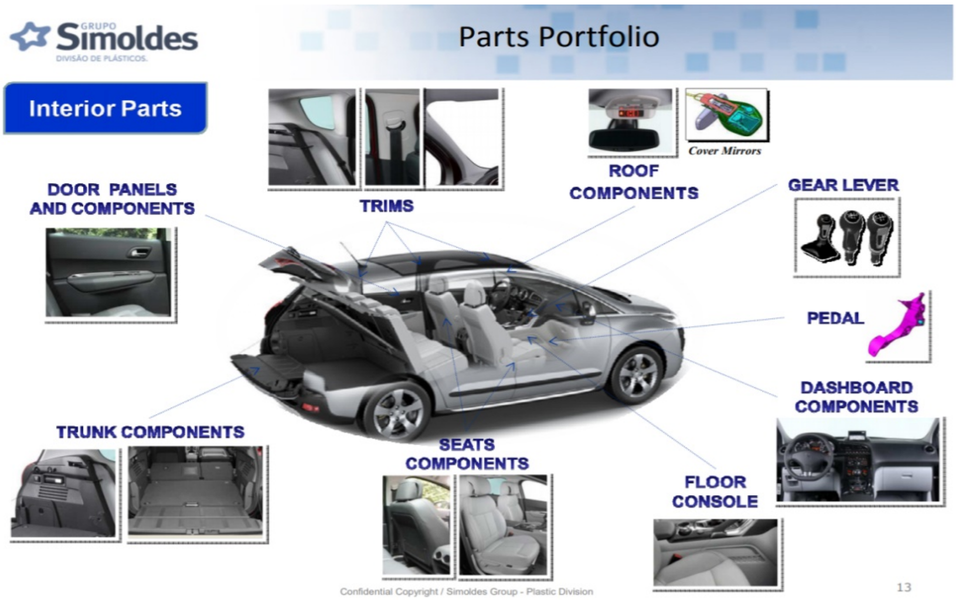


Figure 4 - Products produced by Simoldes

Figure 5 - Products produced by Simoldes

BACKGROUND

3.1 The Injection molding

3.2 Toyota Production System (TPS)

3.3 Lean manufacturing

3.4 Quality tools

3 BACKGROUND

This chapter will provide information about the theoretical framework used in this thesis. Different concepts from well-established theories as well as more recent studies will be described and explored.

3.1 The injection molding

Injection molding is a method of produce a plastic product from a thermoplastic by feeding the material to the machine. The material is placed in the hopper to a heated chamber in order to make it soft and force it into the mold by the rotation of the screw. In all this process, pressure should be constant until the material is hardened and is ready to be removed from the mold. This is the most common, fastest and cheaper way of producing plastic products with any complexity and size. (Samson Teklehaimanot, 2011)

Injection molding permits mass production manufacturing with high precision, using well-known injection machines (Figure 6).

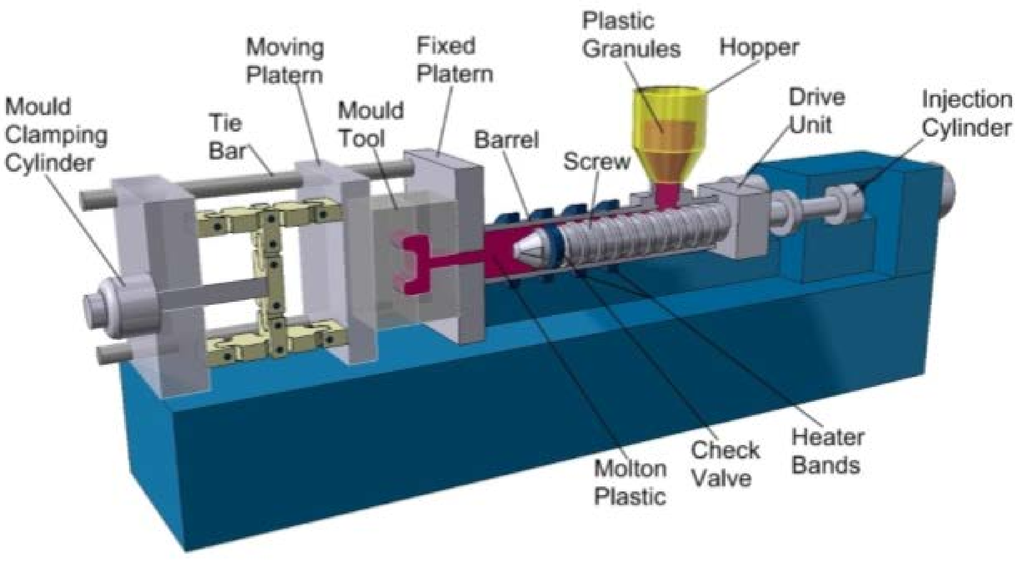


Figure 6 - Injection Molding Machine

3.1.1 The injection molding process

The injection molding process starts with the feeding of a polymer from the hopper to barrel which is heated, then the melted plastic will be injected under high pressure into the mold. During this process there is a constant pressure on both plates of the injection molding machine (moving and fixed platens) to close mold while the plastic is injected, subsequently, the product is set to cool down which helps it in the solidification process. After the product gets its shape and is cold enough, the two plates will move away from each other in order to separate the mold tool which is known as mold opening. Finally, the plastic part is ejected or removed from the mold. After the ejection of the part, the process will repeat itself (Figure 7).

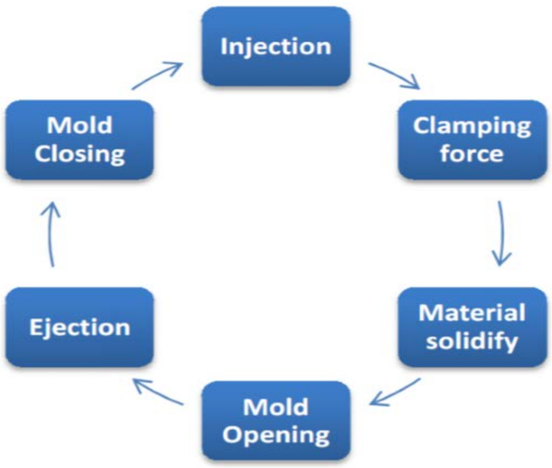


Figure 7 - Injection Molding Cycle

The cycle starts with the retraction of the ejector plate, followed by the closing of the mold. The injection unit melts the polymer and injects the polymer melt into the mold with the rotation of the screw that will push the material through a heat region. The melt plastic is pushed to the nozzle and is injected into the mold.

The molten polymer is forced into the mold in two or three stages:

- Stage 1: Fill stage
    - During this stage, the mold cavities are filled with the melted polymer. As the material is forced forward by the screw, it passes by a spreader, also known as a torpedo, which is inside the barrel and as the objective of mixing. The parameters in this stage are the velocity (rate), the pressure, and the time. Injection velocity is the rate at which the screw moves forward.

- Stage 2: Pack stage
  - o As the melt enters the mold, it cools off and presents shrinkage. The packing stage is essential to force more melt into the mold to compensate for shrinkage.

- Stage 3: Hold stage
  - o When no more material can be forced into the mold we reach the hold stage. In hold stage there are forces against the material in the cavity until the gate freezes, this holding stage prevents leaking of the melt. In some machines, pack and hold are combined in the same stage.

Each stage has specific pressure and time duration (Figure 8). Once the mold is through all the three stages (filled, packed and the gate has cooled), starts the cooling stage. The cooling stage is regulated by the cooling time. After the cycle is complete and before the next cycle, the part should be removed.

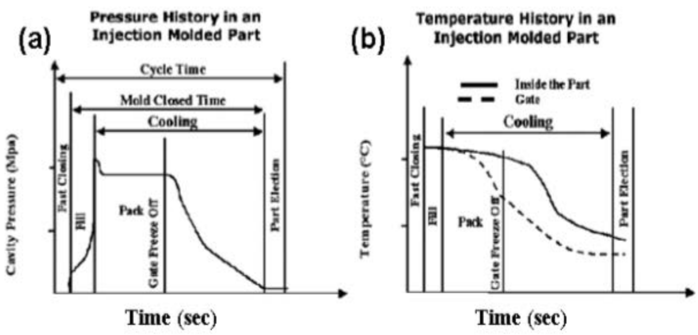


Figure 8 - Typical pressure and temperature cycle of injection molding

3.1.2 Injection molding machine components

The components of an injection molding machine are the hopper, the screw, the barrel and the injection nozzle.

- The Hopper
  - o In the molding process, the hopper receives the plastic materials in form of small pellets. The hopper function is to hold these pellets. The pellets fill the barrel by the gravity force.

- The barrel
    - The main use of the barrel is to give support for the screw. The Barrel has heater bands which function is to control the temperature through the different section of the barrel.

- The Screw
    - The screw is used in compressing, melting and mixing the plastic material (Figure 10). The Screw consists of three zones – feeding zone, transition zone and the metering zone. In the feeding zone, there will be no change to the plastic materials, they will be a force in the barrel through gravity, and will remain pellets until reach to the next zone. The next zone is the transition zone, in this zone the pellets start to melt. The last zone which is the metering zone, the molten material is ready for injection.

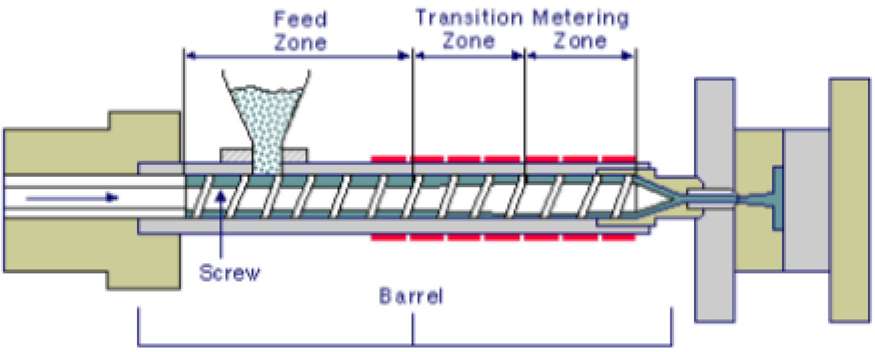


Figure 9 - Different Zones of the Screw

- The Nozzle
    - The main function of the nozzle is in connecting the barrel to the mold through the sprue bushing, creating a seal. It's essential that the temperature of the nozzle should be the same as the materials melt temperature.

3.1.3 Injection parameters

The set of process parameters are those who are defined before the process begins and the operator cannot change them. These parameters are defined in the selection of the equipment and in the project phase of mould.

The most important process parameters are the geometry of the part, the feed system, its geometry and location, the capacity of the injection moulding machine, the geometry of the nozzle and the temperature distribution on the cavity surface.

The variables are the processing conditions that can be adjusted by the operator. The most important variables are temperature profile in the barrel, mould temperature, injection speed, injection pressure, the second pressure, second pressure time, screw rotation velocity, cooling time, open/close velocity, clamping force and cycle time.

The temperature profile of the material along the barrel is due to the heat generated between the polymeric material and the barrel walls and the screw. The profile temperature depends on the material to melt, on the screw geometry and on the cavity geometry. The profile temperature must meet a certain range of temperatures in order to guarantee the flow of the material without causing its degradation. High injection temperatures increase cycle time and the energetic consumption, benefit contraction, brightness and transparency. Low temperatures difficult the filling of the cavity enhancing the weakening welding lines.

The mould temperature influences and determines most of the properties of the injected part because it influences the structural development of the polymer during the cooling phase. The mould temperatures range depends on the nature of the material. The mould temperature varies a lot during the injection cycle. This temperature is regulated during the injection cycle in order to reduce the mould's thermal amplitude. High temperatures increase brightness, contraction and transparency. Low temperatures increase internal tensions.

The injection speed is the progression of the screw across time, so is the mass flow rate that is injected. This processing condition is very important in the process in order to ensure a low flow viscosity and reduce heat losses during the injection phase. However, very high injection speed can cause defects on the mould. The optimal injection speed corresponds to the minimum injection pressure. At the end of the injection, phase is recommended to reduce the injection speed in order to reduce equipment wear. The speed rotation of the screw is important to obtain a homogenous melt along the process. High-speed rotation is used when a fast melt of the raw material is needed.

After the injection phase, the pressure is applied to the cavity. This pressure has the purpose of compensating the volumetric contraction which the material is subject to, during the cooling phase. With the freezing of the material in the gate, the pressure drops and the pack phase ends.

The cooling time is accounted after the end of the pressure phase until the extraction temperature for the material is reached.

The clamping force is required to keep the mould closed during injection process; (it is usually expressed in ton or kN). This force will oppose the pressure exercised by the injected material in the mould cavity. The clamping force must be adjusted to be higher than the required to avoid mould opening during injection (Figure 10).

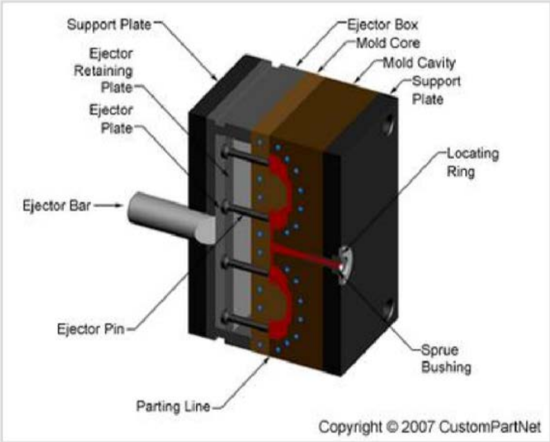


Figure 10 –Cross-section of a mold

3.1.4 Molds: types and general constitution

The mould is the tool where the part is produced. The design of the mould is dependent on the size and shape of the part to produce. The mould may have several cavities and it may vary in the amount of the various constituent elements and their arrangement. The design of the mould depends also on the size and capacity of the injection machine where it will be placed. The thermal properties of the mould material are very important to achieve a good and uniform cooling of the part. Seeing the mould as a heat exchanger the mould material must have good thermal conductivity. Moulds are typically in aluminium, hardened steel and pre-hardened steel. The determining factor in the choice of the material to build a mould is the cost of the material.

The mould splits into two halves. Each half is mounted to the mould base. The mould base is attached to the plates inside of the injection machine. One half of the mould is fixed and the other slides to open and close the mould. The two main components of the mould are the mould cavity and the mould core. When the mould is closed, the space between the half's forms the part cavity, the space that will be filled with the molten material.

The mould cavity includes the mould cavities and the feeding system. The mould core has the ejection system that ejects the solidified part out of the mould.

The nozzle connects the injection machine to the mould and this connection is just made by contact. The temperature of the nozzle is an important parameter, and it must be set close to the melting temperature of the material to facilitate the injection process.

The runner system is responsible for the distribution of the molten plastic flow into the mould cavities. The sprue is the channel where the material flows from the nozzle to the runners. The runners carry the material from the sprue to the cavities. The gate is a small entrance that prevents the material to return to the runner after the injection because it solidifies first because of its small dimension. The material that solidifies inside the runner is attached to the part and it must be separated after the part has been ejected from the mould. The mould also contains the cooling system, a group of channels wherein a fluid flows in order to cool the part. The next figure shows the mould channels and elements. A good injection mould should ensure a good flow of the material as well as an easy removal of the produced part, so the mould walls must have a draft angle. In the design of the mould should be taken into account a good distribution of the feed and cooling channels. It is very important to have a good cooling system, to provide a homogeneous cooling and consequently obtain a quality part. The quality of the part is also influenced by the location of the gate, thickness variations, contraction, warping and gases output, so all of these must be considered in the design of the mould.

Feeding System

The feeding system begins to be designed by defining the gate location for the part and the other elements are placed depending on it. The feeding system must be designed with the objective of guarantee a balanced flow to fill each cavity part ate the same rate. To achieve this goal it must be taken into account if the mould has a single cavity or multiple cavities, the design of the cavity, the location of the sprue in the mould, and the shape of the sprue, runners and gates. The feeding system whenever possible must have short channels and the lowest shot weight. The feeding system can be cold or hot runner system (Figure 11).

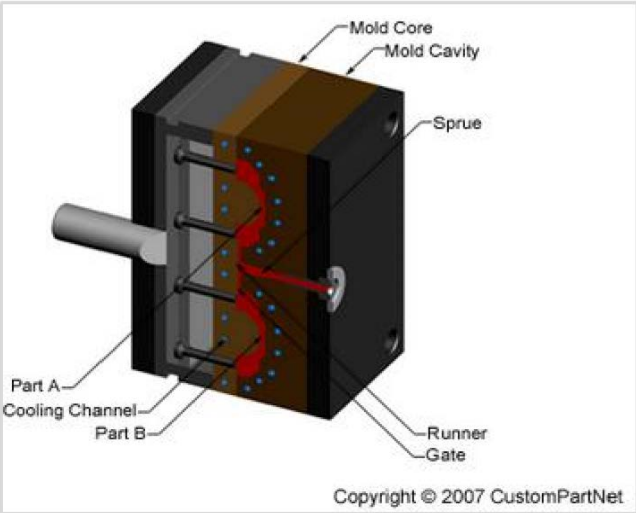


Figure 11 - Mold channels

Cold Runner System

A cold system is constituted by the sprue, runners and gate. It is named cold because the material inside the system is cooled along with the part. Since the material solidifies, to make the extraction easier, the channels of the system must have a draft angle. Besides the draft angle, when designing cold runner system, it is important that has a higher thickness than the part to produce. This ensures that the melted material can be packed into the part and can cool without restriction. The feeding system is ejected with the part and removed after. The removal usually leaves a mark in the part.(Frenkler and Zawistowski, 2001)

- Gate
  The gate (Figure 13) is a small orifice through which the material enters the mould cavity. For each part, it must be selected the type of gate, location and dimensions. Gate design depends on the part specifications, the material, and is very important regarding part quality and productivity. The gate can be a single or multiple. A single gate gives better results "unless the length of the melt flow exceeds practical limits. A single gate ensures a more uniform distribution of material, temperatures, packaging and better orientation effects. Multiple gates create weld lines where the flows from the several gates meet. The cross-section shape defined for the gate must be the same for the other channels of the system. Smaller dimension allows an easy detachment and reduces the visible mark on the part. Gate sizing is adjusted according to the appearance, residual stress and dimensional stability required. The gate location is the best location that guarantees a fast and uniform mould filling. The gate location should be a location with low flow resistance and an area with low external stress since the gate location is a location with high residual stress. The gate is followed by the runners (Figure 13).

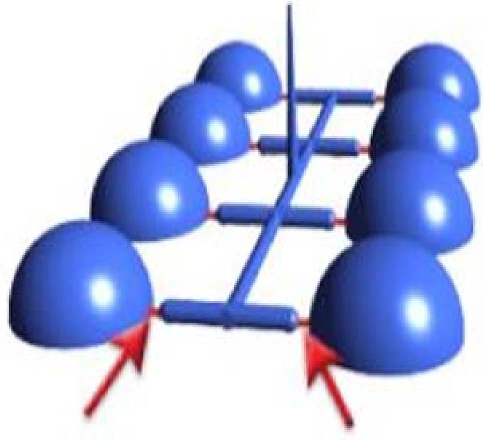


Figure 13 - Gates (feed system element)

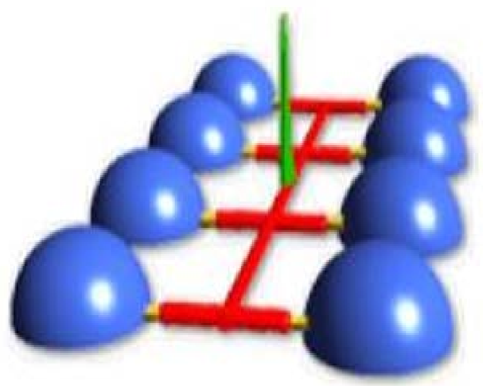


Figure 13 - Runners (feed system elements)

- Runner

  The runners are the channels that direct the melt flow from the sprue to the mould cavity (Figure 13). A proper runner design will allow a balanced filling, an easy ejection of the part, good control of the filling/packing/cycle time and will minimize material and energy consumption. Large runners allow a good flow of material at relatively low pressure, but once they are thicker they require more material, more time to cool and higher clamping force. Small runners maximize material and energy consumption efficiency. However, small runners are constrained by the moulding machine injection pressure capability available on market. A small diameter increases shear heating and the material reaches a temperature higher than in the barrel. This higher temperature can cause the degradation of the material if it exceeds the material limit but reduces residual stress level and the warp. There are several geometries for runners, but the more used and balanced are the circular runners and trapezoidal (Figure 14).

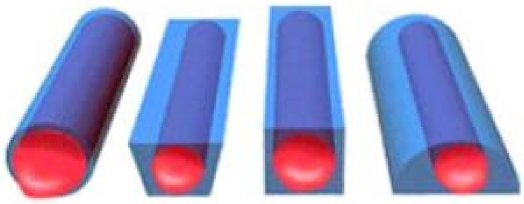


Figure 14 – Cross-section types

  Circular runners minimize pressure drop and heat losses due to have a good volume-to-surface ratio, i.e. the circular cross section provides the greatest proportion of melted material. These type of runners are machined in both halves of the mould (semi-circular sections), that must be perfectly aligned when the mould is closed, what increasing the tooling costs. Trapezoidal runners are machined in one half of the mould and are cheaper than circular runners. This type of runner provides acceptable flow and a good ejection. Trapezoidal runners are used in three-plate moulds, wherein the circular runners cannot be properly ejected or wherein circular runners interfere with the mould sliding action.

- Sprue

  As referred the sprue is the channel that connects the nozzle to the runners. The sprue dimensions depend on the part thickness and it must not freeze before any cross section to guarantee the transmission of holding pressure. The sprue must be easily ejected along the rest of the feed system and therefore has the draft angle (Figure 15).

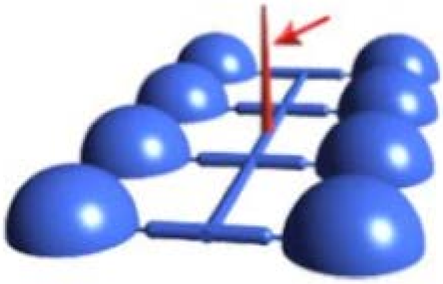


Figure 15 - Sprue (feed system element)

Hot Runner System

The main difference between a hot runner system and the cold runner system is that the material inside the hot runner system stays molten. Due to the material staying molten the draft angle in the channels are not necessary. In this alternative, there is no wasted material. The material stays molten because the channels are heated (internally or externally) or insulated (Figure 16).(Frenkler and Zawistowski, 2001)

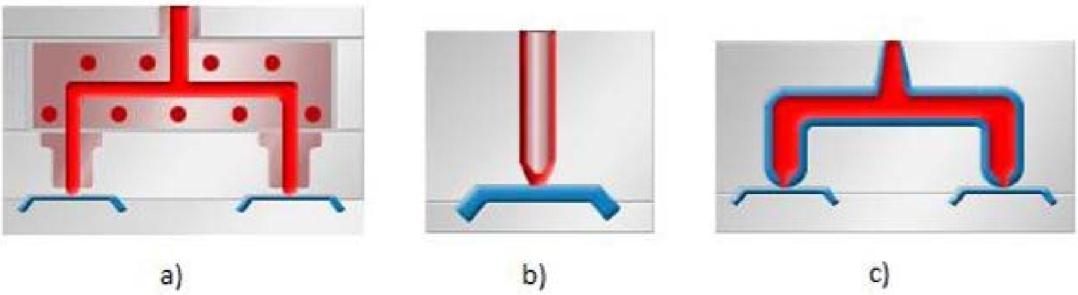


Figure 16 - a) Externally heated; b) Internally heated; c) Insulated

The internal heat is supplied by a probe and torpedo located in circular flow passages and the external heat consists of a cartridge-heated manifold with interior flow passages. The externally heated systems are well suited to polymers that are sensitive to thermal variations. Internally heated systems offer better flow control. The insulation keeps the plastic in a molten state.

Hot runners system is well suited for high volume production of small parts so the price per part decreases and makes the hot runner system more cost-effective. Hot runners allow faster cycle times, better temperature control and a better distribution of heat. The faster cycle times are justified through the smaller cooling time because they're only dependent on the part and not on the runners as cold feed system. Concerning colour material change, it is more difficult to do once the material stays melted inside the runners. This type of runners is not suitable to heat sensitive materials and thermoplastics resins. Designing hot runners should take into account the thermal expansion of various mould components.

Hot runners are used for moulds that have a lot of cavities, for expensive materials and when high quality parts re required, because this type of feed system leaves minimal gates vestiges.

Cooling System

The cooling system has the function of reducing the temperature of the part until the part reaches a temperature where it can be ejected without being damaged. The cooling phase has the greatest importance because it greatly affects the productivity and the quality of the final part, so it must be a commitment between a fast and a uniform cooling. The uniform cooling ensures the part quality by decrease residual stress and keeping dimensional accuracy and stability. Heat transfer is therefore very important in injection moulding (Figure 17).

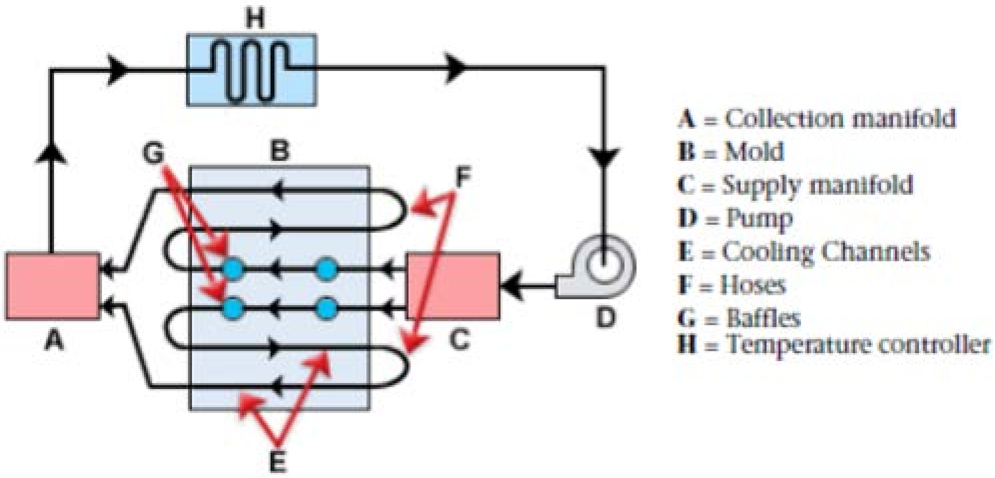


Figure 17 - Cooling system elements

In the design of the cooling channels, there are some parameters that can be improved to have a better and uniform cooling. These parameters are the diameter of the channels, the distance between channels and the mould and also the thermal properties of the mould material. These parameters are constrained by several rules and considerations. The coolant conditions are also very important. To guarantee an effective heat extraction the coolant flow must be turbulent.

The cooling channels configurations are in parallel or in series. The more recommend and used configuration is serial cooling channels.

With research and development of cooling systems regarding channel size, location, coolant flow rate and thermal properties of mould material it led to another type of cooling, the conformal cooling.

Conformal cooling is defined by Lin as channels that should shape the mould cavity surface. The conformal cooling system causes a homogenized cooling of the part because it follows the contour of the part. It is expected that a part with conformal cooling has better surface quality than with conventional cooling.

3.1.5 Surrounding devices

In the first line of action, one have a robot with a specific and unique Handheld (Figure 18) for each part that will extract the plastic part and the sprues in some cases. For safety all the injection cycle system is command by the robot, this means that the mold will not close until the robot gives the signal. With this kind of system, we are not able to close the mold with the robot inside or with the part and sprues inside the mold.

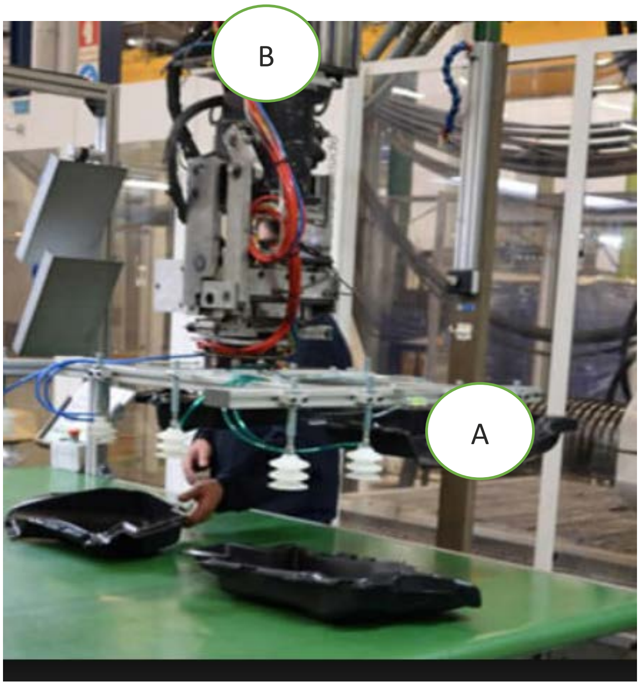


Figure 18 - A) Headheld; B) Robot (Simoldes Robot)

In the second line of action, there are devices responsible to control if the part is complete, responsible to cut the sprues of the parts, responsible to control if the operators assembled all the components.

3.1.6 Usual defects

Defects in injection molding appear mostly because of the mold design imperfection, wrong treatment of the material used and wrong parameters along with non-uniform setting times play the major role in lowering the product quality.

Table 1 highlights some of the problems that might appear in a typical injection. To complete, the table will also show the probable cause and the method to resolve each problem.

Table 1 - Injection problems

Problem	Cause	Possible solutions
Sink marks	Part is under filled	Increase shot size Increase cavity or hold pressure Reduce fill rate Open gates Improper gate location or design
Voids	Part is under filled or has excessive shrinkage	Poor venting Improper gate location Injection rate too high
Shrinkage	Volume decreases as plastic cools Insufficient cooling time	Increase hold time Improperly balanced cavity and core temperature Runners or gates too small
Flash	Insufficient clamping force Leaks in the mold	Increase clamp force Clean mold surfaces Change gate locations
Burning	Compressed air in the mold degrades the resin	Decrease peak cavity pressure Clean vents, increase the size or number of vents Reduce melt temperature
Warp	Non-uniform stress due to excessive orientation	Part ejected too hot (so increase cycle time) Decrease injection fill rate Flow too long, Insufficient gate Change gate location
Brittle parts	Excessive orientation Improper design Degradation of resin	Increase injection fill rate Increase melt temperature Design properly, adequate radii at corners, notches or threads

3.2 Toyota Production System (TPS)

The framework is built around the philosophies in Toyota Production System (TPS). Lean manufacturing is considered to be a western variant of TPS and is therefore included together with TPS in this particular framework. Furthermore, within lean manufacturing a few analysis tools are especially emphasized (Figure 1).

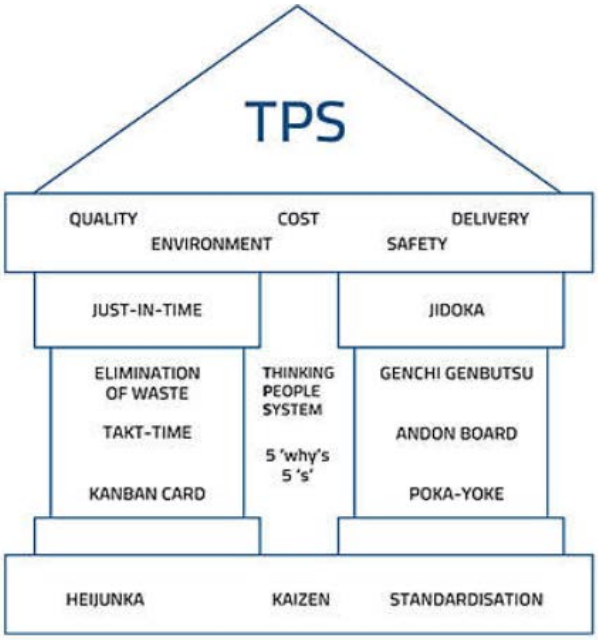


Figure 19 – Toyota Production System and corresponding tools (Monden, 2011)

Toyota Production System is Toyota's approach to manufacturing. Many of the concepts in lean manufacturing come from TPS. TPS has been a major influence on the trends in manufacturing during the last decades. Toyota's methodology to implement a lean concept was very different from other companies. It is possible to allege that a lean enterprise is achieved if TPS is applied to all business areas in a company. Toyota has defined lean manufacturing as a five steps process:

- Defining customer value;
- Defining the value stream;
- Make the value stream flow;
- Pulling from the customer;
- Striving for excellence.

To become a lean enterprise, the company culture also requires that everyone is striving to improve continuously. Taiichi Ohno, one of the founders of TPS, has made the following statement: "All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes." (Liker, 2004).

3.2.1 Waste – Muda

Muda is Japanese for waste and are all activities that do not add any value to the finished product. Toyota was among the first companies that, through TPS, defined the sevens wastes (Hines and Rich, 1997) in a manufacturing environment. Later on, Liker (Liker, 2004) has included another waste, that is the unused employee creativity. These wastes have been translated and interpreted to work in other businesses as well. See next table for description of the eight wastes.

Table 2 - Explanation of the eight wastes (Liker, 2004)(Hines and Rich, 1997)

Wastes according to TPS	**Wastes in general**	**Comment**
Overproduction	Faster than necessary pace	This is the worst waste since all resources used along the value chain becomes unnecessary. Faster than necessary pace discourages a smooth flow and is therefore something to avoid
Waiting	Waiting	Affects both goods and workers
Transport	Conveyance	Transport minimization rather than removal is usually sought. Be aware of double handling and excessive movements
Inappropriate processing	Processing	Occurs when simple procedures have complex solutions, is encouraged by poor layout and communication
Unnecessary inventory	Excess stock	Increase lead times. Problems are often hidden by inventory
Unnecessary motion	Unnecessary motion	Involves ergonomics of products; e.g. operators have to bend, stretch and pick up when they should not. Might lead to poor productivity and quality
Defects	Correction of mistakes	These are direct costs
Unused employee creativity	Unused employee creativity	Not engaging or listening to employees' ideas, or not use their skills, could result in improvement opportunities getting loss

Hines & Rich (1997) have defined three overall categories to describe the nature of activities in a manufacturing context. These categories are value adding activities, non-value adding activities and non-value adding activities but necessary. When referring to waste, value adding activities can be overlooked since these are the activities actually contributing in the transformation of the product from raw material or WIP into a finished product. In other words, the activities the customer in the end is paying for. At the other end of the spectrum there are non-value adding activities, which are pure waste and can come in any of the seven, or eight, shapes listed earlier in this chapter. Lastly there also exist non-value adding activities, which are necessary under the current manufacturing conditions in certain plants. For example, some types of transportation might be necessary in order to move a unit from one position to another or unpacking supplies. These activities are essentially waste but requires large changes in for example layout, which cannot be altered instantaneously.

3.2.2 TPS compared to mass production

TPS can be seen as the opposite of mass production. Instead of economies of scale, spokesmen for TPS advocate a one-piece flow. (Hines and Rich, 1997)

There are many differences between mass production and TPS. For example, the view on machine downtime. Mass production philosophy states that machine downtime is something that should be avoided, because then machines cannot produce parts that could generate money. TPS argue that it is good to have a machine shut down since it can prevent overproduction, and this is one of the most important wastes to address in according to the TPS philosophy. In TPS a company should strive after building up small inventory of finished goods and not produce according to a fluctuating demand. If that is achieved the company is able to level out the production schedule. This leads to small variations in the production schedule and a smooth manufacturing flow. (Liker, 2004)

The major focus of the philosophies is completely different. Mass production focus on everything that is not value adding while TPS focus on everything that is value adding. Instead of trying to identify waste, the overall philosophy of TPS is to identify activities that add value and reduce everything else. (Liker, 2004)

3.2.3 One-piece flow and continuous processes bring problems to the surface

A continuous process with a one-piece flow is the core which many of the lean tools will be implemented since it reveals hidden problems in a manufacturing environment. For example, problems hidden by high inventory levels can be discovered. By “lowering the water level”, in the shape of inventory levels, issues will appear. If they are not investigated and solved, even more problems will occur. Major inefficiencies in companies that are not considered as lean, are hidden in their capacity. These inefficiencies will not be noticed until the water level is lowered and they are brought to the surface.

In many businesses a large part of the processes is waste. The value-added activities are surrounded of waste. In a manufacturing process with a continuous flow the raw material starts to move when a customer places an order. The raw material flows forward to the workstation or the factory where it is needed. Nothing is produced until it is actually needed by the next step of the process. This is the main idea in theory; an uninterrupted production process with no inventory or waiting time between stations.

In a mass production setting it is not unusual to group similar workers or machines together in order to achieve economies of scale and flexibility in scheduling, i.e. no consideration on how the material actually flows. This can result in large amounts of WIP, unnecessary travelling and overproduction.

In TPS there exist no departments or sections with only one type of process, instead there are work cells. These work cells are grouped by product instead of process. A faster flow is the same as a better flow. This is because a faster flow often has higher quality of the products compared to a slower flow. In mass production large batches are produced. If an error occurs it might take long time before it is discovered, and by then a lot of products are already made. In a one-piece flow the time it takes from one station to another is shorter, since only one product has to be produced and not several. Therefore, it will not take that long time until the potential error is detected, and by that point it is easier to detect the root cause of the problem. If products are produced in large batches the error might be detected too late to find out what caused it in the beginning. In this way a faster and continuous flow will be a flow with a higher quality of its products than a slower flow.

One negative aspect with a one-piece flow compared to mass production is that in mass production, one workstation can keep producing even if the previous workstation breaks down, thanks to the high inventory. In a one-piece flow the entire flow stops if one machine is down. The priority in TPS is to not have any intermediary flows that covers the problems. Without exposing the flaws of the flow it is not possible to improve it. This is why continuous improvement is strongly linked together with one-piece flow.

However, Toyota is not applying a one-piece flow if it does not fit but the idea of it is always present within the organization. The idea of one-piece flow creates something to strive after and presents a direction processes should follow. Small batches are better than larger ones, even if it is not a single piece. The smaller the batches are the faster can the production respond to changes in customer demand.

3.2.4 Takt time

If one workstation is made more efficient than the others, the risk is that this workstation will make the overall process more slow, instead of increasing the overall speed. The extra efficient workstation will only add inventory and extra paperwork to the other less efficient stations, resulting in an overall slower manufacturing process. This is why processes or activities need coordination, in order to work as an integrated team of players to achieve maximum total speed. To complete a one-piece flow, the takt time need to be considered. Takt time is the rate of customer demand. By this measurement the speed of production can be determined and in the extension each process can see if they are working too fast, too slow or in the right pace.

An example to describe how takt time works: If a company has 1 shift per day for a certain product and each shift is 8 working hours, which is equal to 480 minutes per day. A month may consist of 20 working days which gives a total of 9 600 working minutes per months. If the demand from customers for that specific product is 19 200 units each month, it leads to a takt time of 2 units each minute (19 200/9 600 = 2). This means that every 30 second a new product should be finished; this is the heartbeat of the production and the takt that all processes should relate to.

3.2.5 Just In Time (JIT)

Just in Time (JIT), is a fundamental principle of the TPS and is based in Toyota's pull system. If JIT should be described by one sentence it is that JIT is the way of deliver the right items, in the right amount and at the right time. To be able to be responsive to customer demand, JIT is an essential part and it is applicable both internally and externally. Customers can be external but also internal inside the company and should be provided with the same services as the external ones.

If JIT is fulfilled it is possible to keep a low WIP. A high level of WIP increases the capital accumulation in the production and handling of material. In JIT production the following workstations gets information from the previous one with a kanban system, described in the upcoming chapter. To succeed in JIT, good production conditions are required.

3.2.6 Kanban

In a one-piece flow, the ideal state should be a process that gets its units in the exact time, quantity and quality as the process requires it. This is a pure pull system. Instead of pushing products forward along the flow of a process, let the stage before know when the units are wanted. In that way the flow does not run the risk of having too many units pushed forward to the next station. Therefore, no inventory is built up.

However, there are some issues with no inventory at all. Ohno recognized that some inventory is needed to keep a smooth flow. The decision Ohno made was to create small inventory points between the processes. When the inventory level is low enough it gets replenished and if it never sinks it never get replenished. In order to signal to the different processes when it was time to refill the inventory, some sort of signal system was needed. This is how Toyota came up with their kanban system.

The kanban let the process know exactly what amount that has to be produced and when it should be produced. It is important to point out that not every process can be used with a pure pull system. Some processes need a push system with an actual schedule in order to work. Nevertheless, Toyota strives towards a true one-piece flow and that includes pull system. In the extension this means elimination of all inventories, if it is possible. It is only when no inventory exists that an enterprise can have a true one-piece flow. Even if it impossible to achieve, a company that seeks a one-piece flow should always try to eliminate inventory where it is possible.

When there are no ways to realize a true one-piece flow, a pull system should be implemented instead. Even if kanban is a good system, keep in mind that all types of inventory are waste, so even kanban. A company should therefore not be satisfied with its kanban system; it should get rid of it if the company truly seeks to become a lean enterprise. Despite this, every company is different and has a specific need and a unique position, therefore some compromises and combinations might be the best in each specific case. Even Toyota uses some type of push system, to achieve harmony of their business in the big picture.

To match different needs in different companies, several kanban systems have been developed. Within a factory, variants called withdrawal kanban and production kanban are commonly used. In these Kanban systems, a storage point such as the supermarket is preferred. A supermarket is a storage point of standard inventory, with the purpose to provide downstream processes with material when needed. A supermarket does not replenish goods on the shelves until they are almost empty.

The withdrawal kanban is representing the customer manufacturing process and is used to signal for material from the supermarket. Production kanban can be seen as an internal supplier in the factory with the main task to replenish the supermarket with material when needed. In other words; the material is being pushed into the supermarket by the use of production kanban and pulled from it with withdrawal kanban.

Cards that can be passed on from stations in the customer process to the supermarket can be used in a kanban system but the important thing is to have some sort indicator that alerts the supermarket to deliver material in a system of withdrawal kanban. Similarly, can an indicator designed to the production from the supermarket be put into motion when replenishment is needed in the supermarket, i.e. to support the production kanban system. To clarify; the kanban signal does not have to be cards. It can for instance be containers or boxes. It is central to have the kanban designed to the specific parts it is signalling for.

3.2.7 Heijunka

Heijunka describes how to level out production and is therefore related to takt time. The best way, according to a lean perspective, is to produce orders when the customer wants it. However, customers do not order the exact same number of products from week to week. In many businesses can be the opposite, the demand changes very much from one week to another. These challenges strive towards a balanced production with a one-piece flow without intermediary inventory.

If production is not levelled out, the workers might need to work overtime and the week after they might have nothing to do and workers and machines are not utilized. The amount of raw material or other material bought from suppliers are also something that will get the company in trouble since the fluctuations in demand will lead to very large changes in what will be ordered.

If the total numbers of orders in a time period are studied, it is possible to level out these orders in a given set of time with the same number of work orders in production each day. Then the workstations will carry out their work in roughly the same time, which support a smooth flow. Heijunka is very important but can seem like the opposite of lean thinking, especially when customer demand is very unsecure. If this is the case the company is forced to keep some inventory of finished goods in order to have an even level of production. As described many times before, inventory is waste! It is important to serve the customer and a company can in general not rely on zero inventory to satisfy all customers. By keeping this small amount of finished goods, the company can maintain a production that is levelled out and eliminate far more muda in all the previous steps in the production process than the inventory in the finished goods warehouse adds up to. A successful TPS can therefore be a combination, as long as it is combined in the right way, between make to order and make to stock.

3.2.8 Make tasks standardized in order to improve continuously

Standardized work first got its major breakthrough with the mass production concept, but it is also an important part of TPS. Toyota implemented standardized work into all processes, shop floor as well as engineering. Until work is standardized it is hard to improve it and to make the improvement last. If a defect appears, it might be because the standard procedure was not followed. If it is followed and errors still occur, then the standardization of that particular task might need to be investigated and changed.

Toyota recognizes that in order to survive year in and year out and be successful, continuous improvements needs to be based on standardized work. The trade-off regarding the standardized process is the degree of procedures that need to be followed to the letter and the degree of flexibility the workers have to be creative and might come up with improvement suggestions that will lead to an improved process and in the extension contribute to the continuous improvement of TPS.

3.2.9 Visual control and 5S

5S represents Japanese words that describe the steps of a workplace organization process. English equivalent words are shown in parenthesis

- Seiri (Sort);
- Seiton (Straighten, Set);
- Seiso (Shine, Sweep);
- Seiketsu (Standardize);
- Shitsuke (Sustain).

In simple terms, the five S methodology helps a workplace remove items that are no longer needed (sort), organize the items to optimize efficiency and flow (straighten), clean the area in order to more easily identify problems (shine), implement colour coding and labels to stay consistent with other areas (standardize) and develop behaviours that keep the workplace organized over the long term (sustain).(Line, 2007)

Here is a breakdown of each ‘S’

1. Sort (seiri) – Distinguishing between necessary and unnecessary things, and getting rid of what you do not need (Figure 20).

- Remove items not used in area – outdated materials, broken equipment, redundant equipment, files on the computer, measurements which you no longer use;
- Ask staff to tag all items which they don’t think are needed – this improves understanding about need and use;
- Classify all equipment and materials by frequency of use to help decide if it should be removed – place ‘Red Tag’ on items to be removed;
- Establish a ‘holding area’ for items that are difficult to classify – hold item for allotted period to enable others not on 5S team to review.

Figure 20 - 1S - Seiri (sort)

2. Straighten (seiton) – The practice of orderly storage so the right item can be picked efficiently (without waste) at the right time, easy to access for everyone. A place for everything and everything in its place" (Hines and Rich, 1997) (Figure 21).

- Identify and allocate a place for all the materials needed for your work;
- Assign fixed places and fixed quantity;
- Make it compact;
- Place heavy objects at a height where they are easy to pick from;
- Decide how things should be put away and obey those rules.

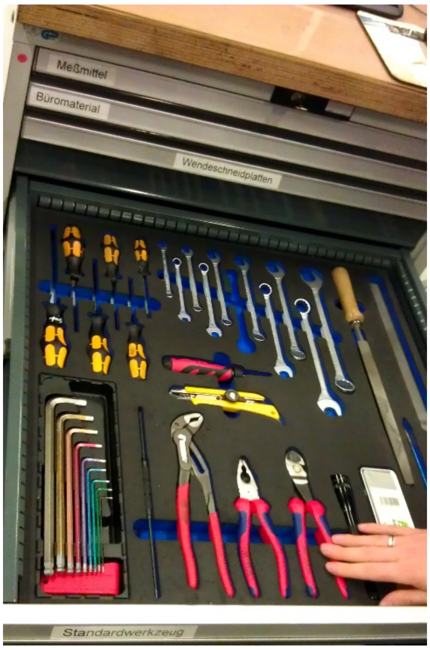


Figure 21 - 2S - Straighten (seiton)

3. Shine (seiso) – Create a clean worksite without garbage, dirt and dust, so problems can be more easily identified (leaks, spills, excess, damage, etc.) (Figure 22).

- Identify root causes of dirtiness, and correct process;
- Only one work activity on a workspace at any given time;
- Keep tools and equipment clean and in top condition, ready for use at any time;
- Cleanliness should be a daily activity – at least 5 minutes per day;
- Use chart with signatures/initials shows that the action or review has taken place;
- Ensure proper lighting – it can be hard to see dirt and dust.

Figure 22 - 3S – Shine (seiso)

4. Standardize (seiketsu) – Setting up standards for a neat, clean workplace (Figure 23).

- Standardization of best practices through 'visual management';
- Make abnormalities visible to management;
- Keep each area consistent with one another;
- Standards make it easy to move workers into different areas;
- Create process of how to maintain the standard with defined roles and responsibilities;
- Make it easy for everyone to identify the state of normal or abnormal conditions – place photos on the walls, to provide visual reminder.

Figure 23 - 4S - Standardize (seiketsu)

5. Sustain (shitsuke) – Implementing behaviours and habits to maintain the established standards over the long term and making the workplace organization the key to managing the process for success (Figure 24).

- Toughest phase is to Sustain – many fall short of this goal;
- Establish and maintain responsibilities – requires leader commitment to follow through;
- Every one sticks to the rules and makes it a habit;
- Participation of everyone in developing good habits and buy-in;
- Regular audits and reviews;
- Get to root cause of issues;
- Aim for higher 5S levels – continuous improvement.

Figure 24 - 5S - Sustain (shitsuke)

3.2.10 The learning organization

Many years back, a company could make good profits just by the revenue from the company's most value product or shop, year in and year out. Today a company needs more than a good shop and manufacturing to survive and the old way of doing business is no longer sufficient. To survive today, the company needs to learn and improve continuously.

When a process is stable and standardized, and only then, continuous improvement can occur. Continuous improvement comes from the Japanese word kaizen. Kaizen exposes the root cause of a problem by asking "why" five times. This analysis strives to get a deep understanding of how a problem can happen and then how it can be prevented. A process that is improved, but not standardized, will as time goes by loose the improvement. Later on, all the improved work will be forgotten, and the process is back to where it started from.

To truly become a learning organization is not something that happens overnight, it is a very long and continuous journey. For Toyota it has taken almost 100 years and the company will most likely need another 100 to carry on the improvement of the organization.

3.3 Lean manufacturing

The topics discussed previously about TPS are highly relevant for lean manufacturing, since lean manufacturing is considered to be a western adaption of TPS. The main parts of TPS and the overall philosophy of reducing waste is also the main philosophy in lean manufacturing.

Lean manufacturing was stated for the first time in the late 80's in an international study regarding the automotive industry. The basic idea with lean production is to use less of everything compared to mass production, less human effort, engineering hours, space in factory and so on, which requires less inventory and defects to succeed. The resources the company possesses need to be used in an efficient way. It is important to keep in mind that lean production is not the same as minimizing the resources used; it advocates efficient use of resources.

Lean is not just connected to machines in the production; all the production resources of the company are included, for example personnel, capital and energy. Today the lean concept is used in many different areas regarding improvements and the original meaning of the concept may have lost its meaning. Lean is the continuing of different improvement programs such as JIT and Total Quality Management (TQM). There are several improvement measures that support lean. Lean cover improvements regarding time, quality and cost efficiency.

3.3.1 Analysis of flows

By analysing the material flow throughout the production site, potential improvements areas can be found. The most critical process can be identified and how other process support the most critical one. In the material flow chart, operations and inventory points are often specified. A good tool to visualize the flow by is the so-called spaghetti diagram.

Spaghetti diagram

This tool basically works as follows; all of the concerned flows are drawn as lines on a layout over the investigated area, which in a factory often results in a large complex web of different flows crossing each other. This complex web of flows has the resemblance of lots of spaghetti strings and therefore the name spaghetti diagram(Juran and Godfrey, 1998).

Possible flows to map could be material flow, administrative flow or the flow of people walking at work. The flows' distances could then be measured to get an idea of how much transportation is carried out in the investigated area (Figure 25).

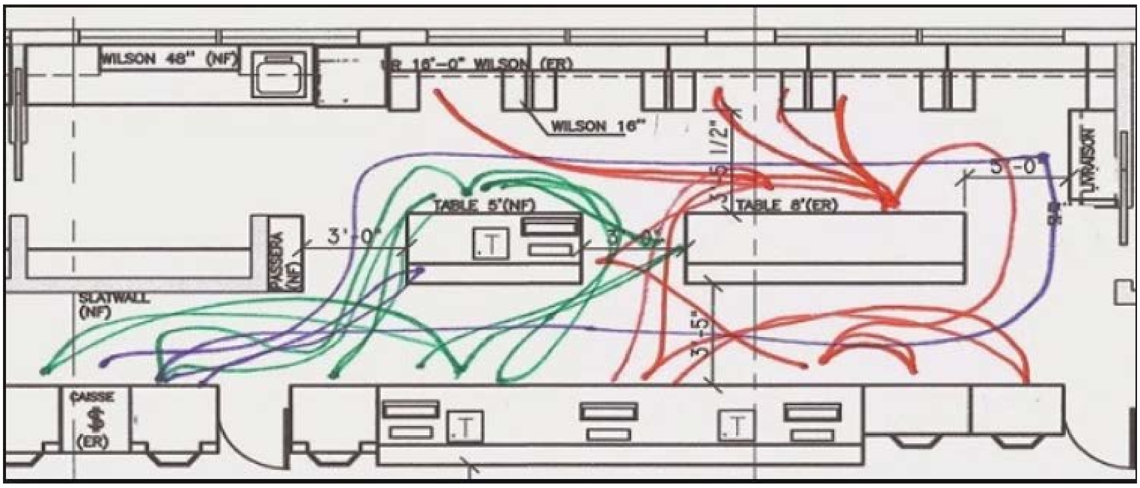


Figure 25 - Spaghetti diagram

3.3.2 Value Stream Mapping (VSM)

Value stream mapping comes from the concept Material and Information Flow Mapping, which has its origin in the Toyota Production System. The fundamentals of eliminating waste, facilitating smooth flow and adding value to the customer are the same within both material flow mapping and value stream mapping. The use of VSM as a lean tool was actually made popular by Rother and Shook in their article Learning to See – Value Stream Mapping to Create Value and Eliminate Muda published. Since then, the value stream map has evolved into one of the most important tools within.

To fully understand the concept of VSM the phrase value stream need to be clarified. Value stream translates the purpose of a firm that adds value to a certain product or service. A value stream is the entire set of activities, i.e. both value adding and non-value adding.(Silva, 2009). There are three categories of activities that are possible in a value stream: value adding, non-value adding and non-value adding but necessary.

Despite slight variations in definitions of what is included in a value stream, the purpose of a VSM is consistent among several researchers within the field. The purpose of a VMS is to identify wastes or *muda* in the company processes and take actions to eliminate them.

Besides sharing the recently mentioned fundamentals with Material and Information Flow Mapping from TPS, a VSM can be defined as a tool that supports the visualization of the complete manufacturing process. Both in terms of material flow and information flow. A VSM should be able to show the entire picture of a productions process; a VSM is not a tool for isolated and individual events.

Since lean manufacturing mostly are known as the reduction of the eight wastes and VSM is considered to be an efficient method to facilitate the removal of waste. VSM is also considered to be a strong method to facilitate lean manufacturing.

How to use a value stream map

To use the VSM properly, it is not enough to only draw one map over the current state. Is recommended four steps when using a VSM (Figure 26).

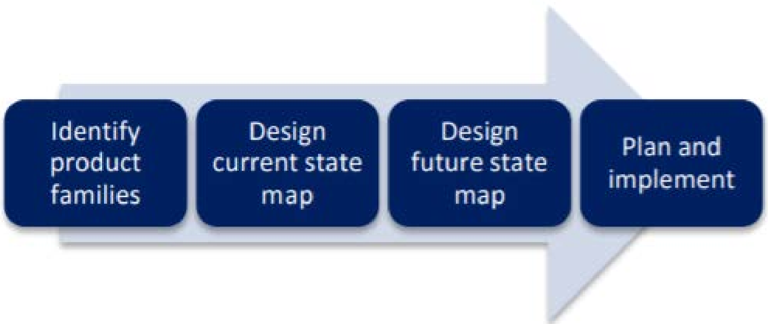


Figure 26 - The process of performing a VSM. (Rother & Shook, 1999)

When creating a VSM it is suggested to focus on a single product within a certain product family to represent the whole product family. The data collected on this single product, and the following conclusions, is then generalized to the rest of the product variants within the same product family.

Once product families have been sorted out it is time to start to draw the first map, the current state map. To aid the creation of an accurate VSM of the current state it is advised to be consistent in the use of different symbols and data in the map. When selecting the data in the current state map, the most important criteria is that it later should be able to work as material for the future state map. See in Figure 27 and Figure 28 examples on how the symbols in a current state map could be designed and a basic example of a current state map.

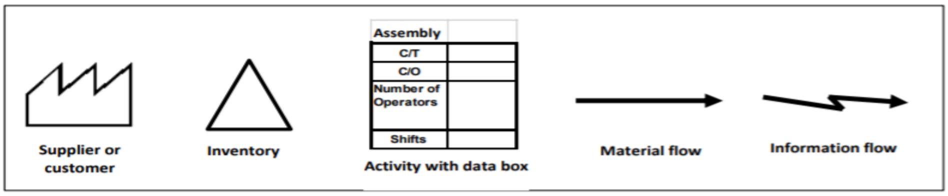


Figure 27 - Exemples of symbols in a VSM

When the current state map is finished and followed by thorough analysis it is time to construct the future state map. The main purpose of the future state VSM is to display a future scenario where the majority or all of the identified waste is removed. The map can work as a vision guiding the company towards an ideal state. It can also be a map with proposals possible to implement in the near term. Independent of the details in the structure, it is important to make sure to address all of the possible wastes by its root causes. A common mistake is to only take care of evident waste by the surface when designing the future state and forgetting to analyse the root causes of a process's problems.

A necessary step towards a complete future state VSM is to calculate the takt time. By calculating the takt time the pace of the production process can be identified.

Besides calculating the takt time in the future state map, additional vital aspects to consider when designing the future state map is to ensure continuous flow of products to as high degree as possible and to use supermarket where continuous flow is not possible. For example, sometimes a factory could contain constraints that prevent it from having a continuous flow through the entire process. Reasons to this could for instance be when a process has very long lead time or simply has unreliable demand, which makes it difficult to couple this process with another one and achieve a continuous flow. In those cases the idea of introducing a supermarket with a pull effect is an appropriate choice. A common way of designing such flow is to use withdrawal kanban from the downstream process to the supermarket and production kanban from the supermarket to the upstream process.

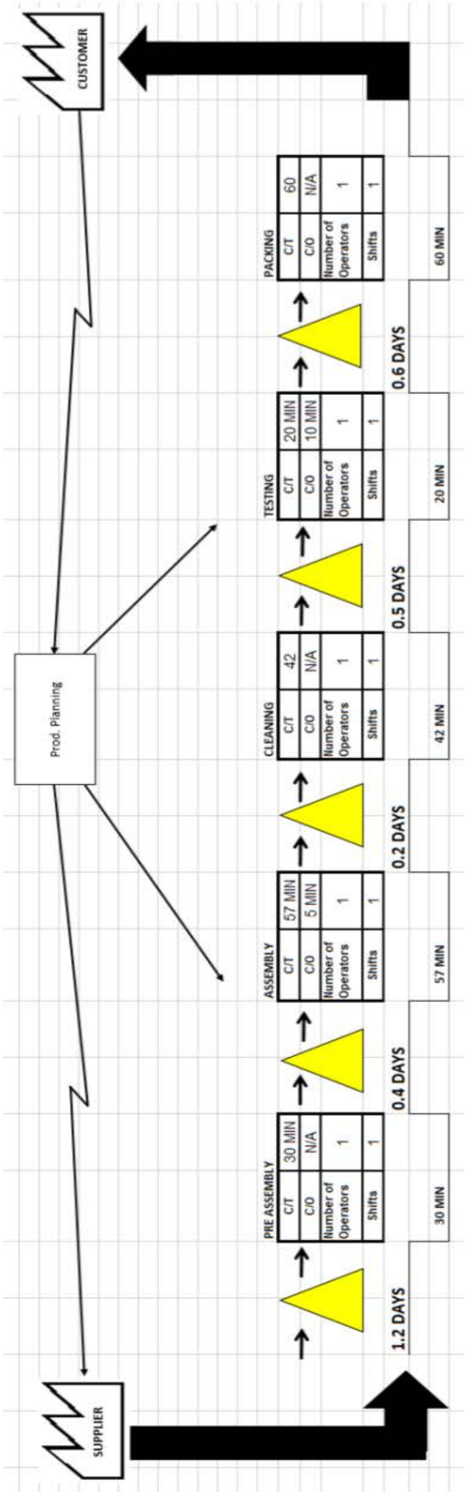


Figure 28 - Example of VSM (Manuel Silva, 2009)

Typical symbols occurring in a future state VSM is illustrated in Figure 29.

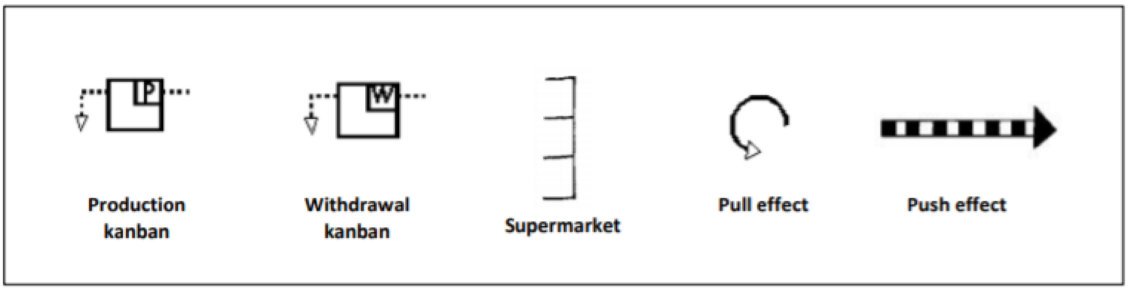


Figure 29 - Examples of symbols in a VSM

Finally, a plan to implement the changes suggested in the future state is required. In most cases companies do not have the resources to transform its company completely at once. It is advised to carry out the proposed changes in a stepwise manner. The mindset when conducting this stepwise implementation should be to implement one flow at the time, i.e. build the future state by implementing one smaller process at the time and then connect them all together once they are completed.

3.3.3 OEE

OEE (Overall Equipment Effectiveness) is a metric that identifies the percentage of planned production time that is truly productive (Figure 30). The formula to calculate OEE is below.

$$\textbf{OEE} = \text{Availability\%} \times \text{Performance\%} \times \text{Quality\%}$$

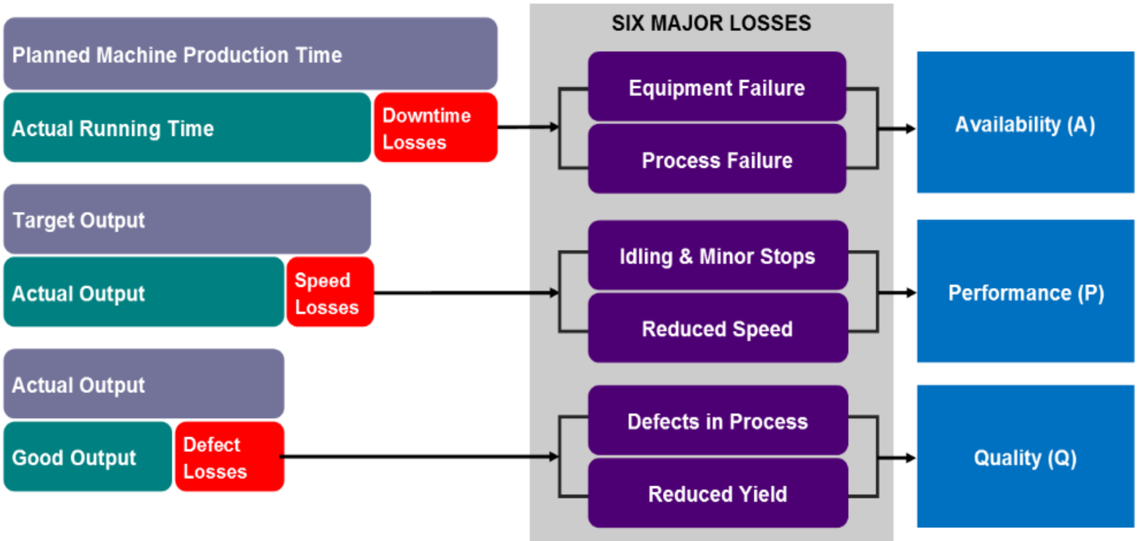


Figure 30 - OEE chart

By using the OEE, is possible to calculate the effectiveness of any process and to detect the respective losses (Figure 31).

SIX MAJOR LOSSES	
Equipment Failure	Breakdown losses due to sudden and unexpected equipment failure.
Process Failure	Also called 'Setup and Adjustment losses', occur when production is changing over or adjustments made for correct positioning.
Idling and Minor Stops	Losses occur when production is interrupted by small problems such as parts that block sensors or get caught in chutes.
Reduced Speed	Losses occur when actual operating speed falls below the equipment's designed speed.
Defects in Process	Losses occur when products do not meet quality specifications which need to be reworked.
Reduced Yield	Yield losses occur when equipment start up is not immediately stable, so the first products do not meet specifications.

Figure 31 - OEE - six major losses

3.4 Quality tools

3.4.1 Pareto's Diagram

Pareto's analysis is a statistical technique used to help us to figure out which problems need our attention right away. They're based on the idea that most of problems are caused by a small number of causes which is based on the Pareto Principle. The Pareto Principle also known as the 80/20 rule, basically It says that 80 percent of the problems are usually caused by 20 percent of the causes (Figure 32).

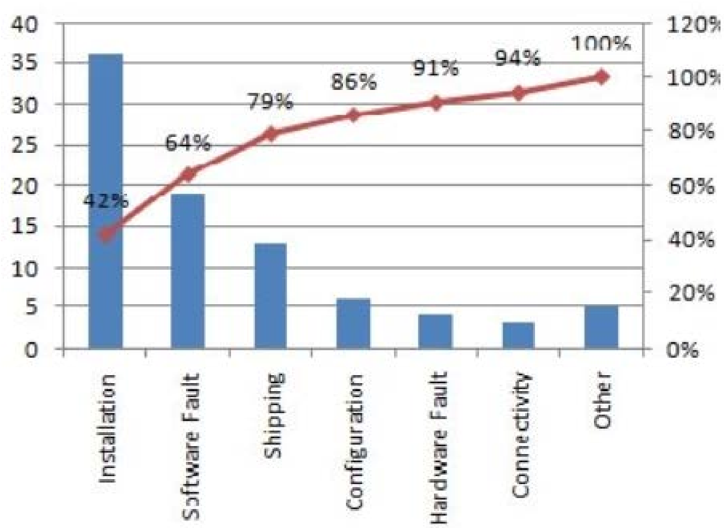


Figure 32 - Pareto diagram

For example, the Pareto charts showed above, shows the frequency of product faults sorted in descending order. This example chart shows that there are problems in 7 categories different categories. As we can observe, most of the product problems are caused by installation issues. Also, the Software faults and shipping faults have a big impact on the complains of the costumers.

Analysing the chart, we can clearly see that there are 3 categories that combined account for causing 79% of faults in the product. So, what this company should do is to focus on these 3 critical categories in order to prevent failure of the product in the market.

3.4.2 Ishikawa's Diagram – Cause and effect diagram

Ishikawa diagram also known as cause and effect diagram or as fish-bone diagram, shows the possible causes of a problem (Figure 33). The way to use this tool is:

- Firstly, you need to first identify the problem that you are trying to resolve.
- Secondly, you will list the major causes of the problem on the spine of the fish, this causes are separated into categories like people, process, materials, environmental, management and equipment.
- The last step is to identify the causes through brainstorming with a group familiar with the problem.

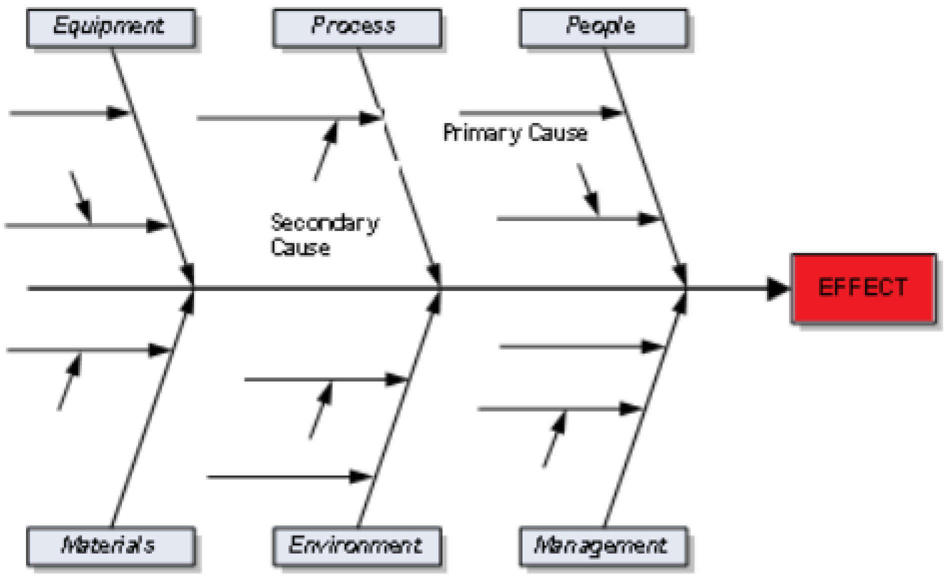


Figure 33 - Cause and effect diagram

Once all the possible causes are identified, they can be used to plan an improvement that will help resolve the identified problem.

3.4.3 Statistical control charts

Control Charts are a way to see how processes are doing overtime. Control Charts measure the results of processes over time and show the result in graph form to show if the process variance is in control or out of control (Figure 34).

A process is in control if the measurements are within the control limits. In a control Chart, is showed a average, a Lower control limit and an Upper control limit.

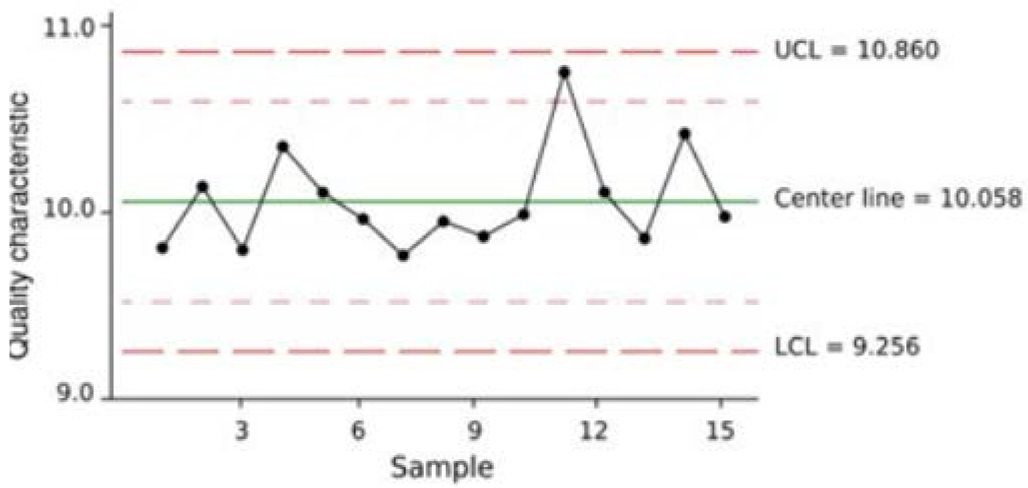


Figure 34 - Control chart

The figure above shows control limits as red dashed lines. The mean is the solid green line in the middle.

As we can see in the chart above, there are a lot of data points which are above and below the average, however they are still between the control limits.

When a data point is outside of the control limits, is named as a point out of the control and is necessary a corrective action in order to control the process.

THESIS DEVELOPMENT

4 THESIS DEVELOPMENT

This chapter aims to analyse the manufacturing processes of VW Tiguan` *Einstiegsleisten*. Besides the characteristic of the current situation of production is proposed and analysed other productive solutions.

4.1 Presentation of the product – VW Tiguan *Einstiegsleisten*

The plastic part *Einstiegsleisten* is located under the door of the car. This part is mainly visible when the door of the car are open. There are different types of parts depending on the version of the Tiguan, there are *Einstiegsleisten* with LED and *Einstiegsleisten* just with the aluminium protection.

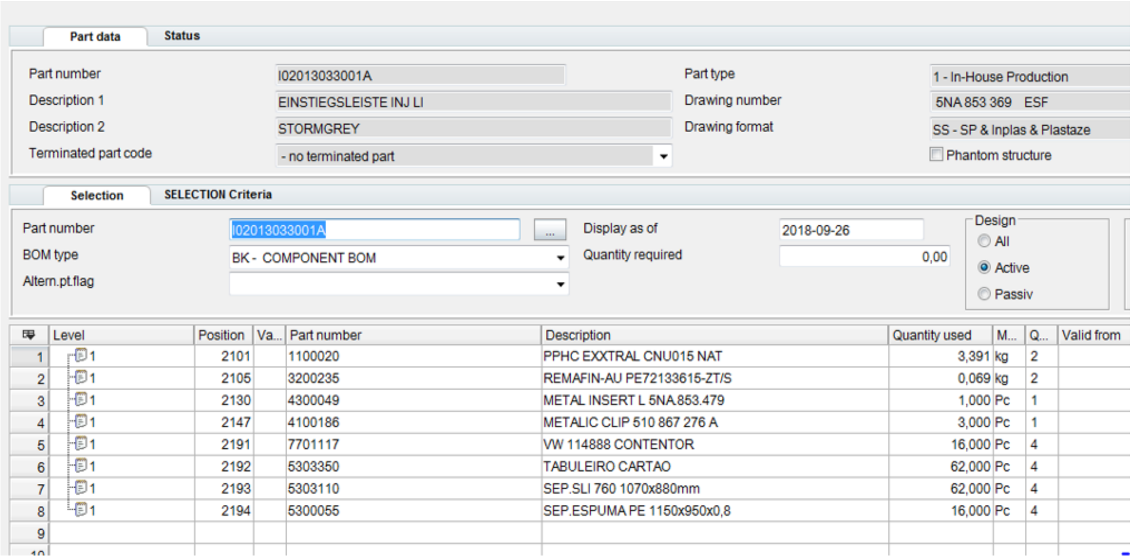
Figure 36 - VW Tiguan` *Einstiegsleisten* R-Line

Figure 35 - Plastic part - einstiegsleiste

“The first thing you see as you open the driver’s door to get in or out of the R-Line is the stylish aluminium door sill protectors complete with the ‘R-Line’ logo. These stylish protectors not only look good but protect the sills from the scuffs and scrapes of everyday use.” (VW Tiguan brochure)

The next table shows the BOM of one of the four possible I-codes, (semi-finished product, not ready to shipment), this plastic part will be used in all our F-codes. There are four I-codes because of the sides, left and right, and the colour.

The BOM to produce one I-code of *einstiegsleiste stormgray* (color of the plastic part) left side there is necessary the Raw Material after treatment plus one additive, plus one metal insert left side and three metal clips. It will be needed as well as packaging components such as container 888, separators, "tabuleiros" (portuguese name define to the cartoon separator used for packaging) and foam.



Part data | Status

Part number: I02013033001A
Description 1: EINSTIEGSLEISTE INJ LI
Description 2: STORMGREY
Terminated part code: - no terminated part
Part type: 1 - In-House Production
Drawing number: 5NA 853 369 ESF
Drawing format: SS - SP & Inplas & Plastaze
Phantom structure

Selection | SELECTION Criteria

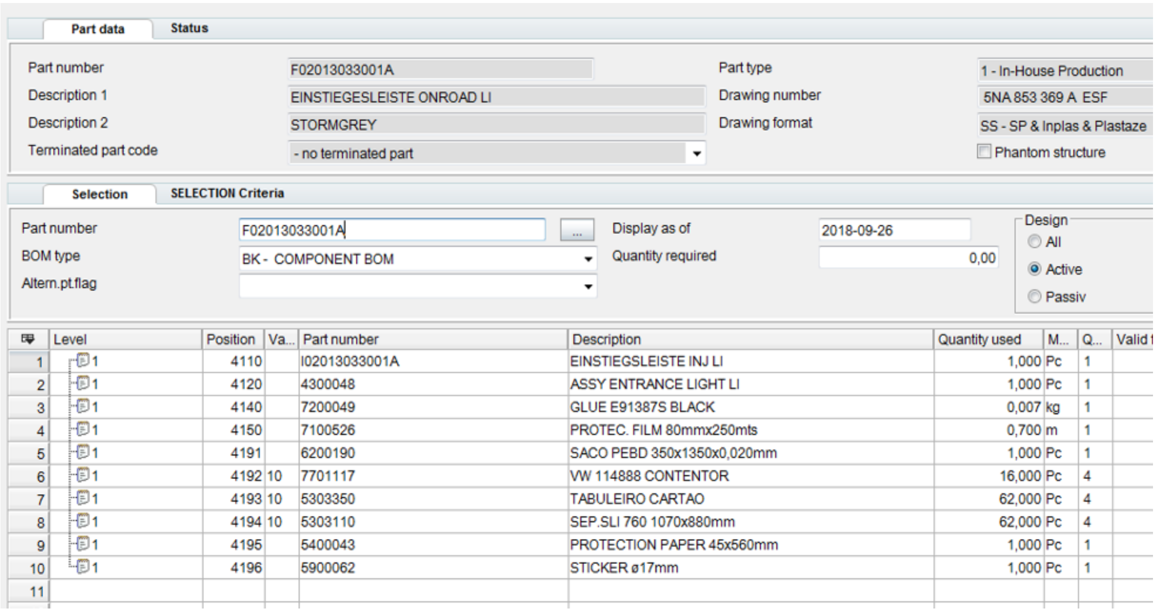
Part number: I02013033001A
BOM type: BK - COMPONENT BOM
Altern.pt.flag:
Display as of: 2018-09-26
Quantity required: 0,00
Design: All / Active / Passiv

	Level	Position	Va...	Part number	Description	Quantity used	M...	Q...	Valid from
1	1	2101		1100020	PPHC EXXTRAL CNU015 NAT	3,391	kg	2	
2	1	2105		3200235	REMAFIN-AU PE72133615-ZT/S	0,069	kg	2	
3	1	2130		4300049	METAL INSERT L 5NA.853.479	1,000	Pc	1	
4	1	2147		4100186	METALIC CLIP 510 867 276 A	3,000	Pc	1	
5	1	2191		7701117	VW 114888 CONTENTOR	16,000	Pc	4	
6	1	2192		5303350	TABULEIRO CARTAO	62,000	Pc	4	
7	1	2193		5303110	SEP.SLI 760 1070x880mm	62,000	Pc	4	
8	1	2194		5300055	SEP.ESPUMA PE 1150x950x0,8	16,000	Pc	4	
9									

Figure 37 - BOM of I-code of einstiegsleiste stormgray left side

The next BOM is about the F-code. There are 24 F-codes that will depend on the side (right or left), the colour (*titanschwarz or stormgrey*) and the version of the LED.

To have one F-code of *einstiegsleiste stormgrey* left side version ONROAD is necessary one I-Code of *einstiegsleiste stormgray* left side, one left LED, Glue, protective film, sticker. And is needed packaging components such as container 888 (standard container used in Simoldes) , separators, "tabuleiros", foam and a plastic bag.



Part data | Status

Part number: F02013033001A
Description 1: EINSTIEGESLEISTE ONROAD LI
Description 2: STORMGREY
Terminated part code: - no terminated part
Part type: 1 - In-House Production
Drawing number: 5NA 853 369 A ESF
Drawing format: SS - SP & Inplas & Plastaze
Phantom structure

Selection | SELECTION Criteria

Part number: F02013033001A
BOM type: BK - COMPONENT BOM
Altern.pt.flag:
Display as of: 2018-09-26
Quantity required: 0,00
Design: All / Active / Passiv

	Level	Position	Va...	Part number	Description	Quantity used	M...	Q...	Valid f
1	1	4110		I02013033001A	EINSTIEGSLEISTE INJ LI	1,000	Pc	1	
2	1	4120		4300048	ASSY ENTRANCE LIGHT LI	1,000	Pc	1	
3	1	4140		7200049	GLUE E91387S BLACK	0,007	kg	1	
4	1	4150		7100526	PROTEC. FILM 80mmx250mts	0,700	m	1	
5	1	4191		6200190	SACO PEBD 350x1350x0,020mm	1,000	Pc	1	
6	1	4192	10	7701117	VW 114888 CONTENTOR	16,000	Pc	4	
7	1	4193	10	5303350	TABULEIRO CARTAO	62,000	Pc	4	
8	1	4194	10	5303110	SEP.SLI 760 1070x880mm	62,000	Pc	4	
9	1	4195		5400043	PROTECTION PAPER 45x560mm	1,000	Pc	1	
10	1	4196		5900062	STICKER ø17mm	1,000	Pc	1	
11									

Figure 38 – BOM of F-code of *einstiegsleiste stormgrey* left side version ONROAD

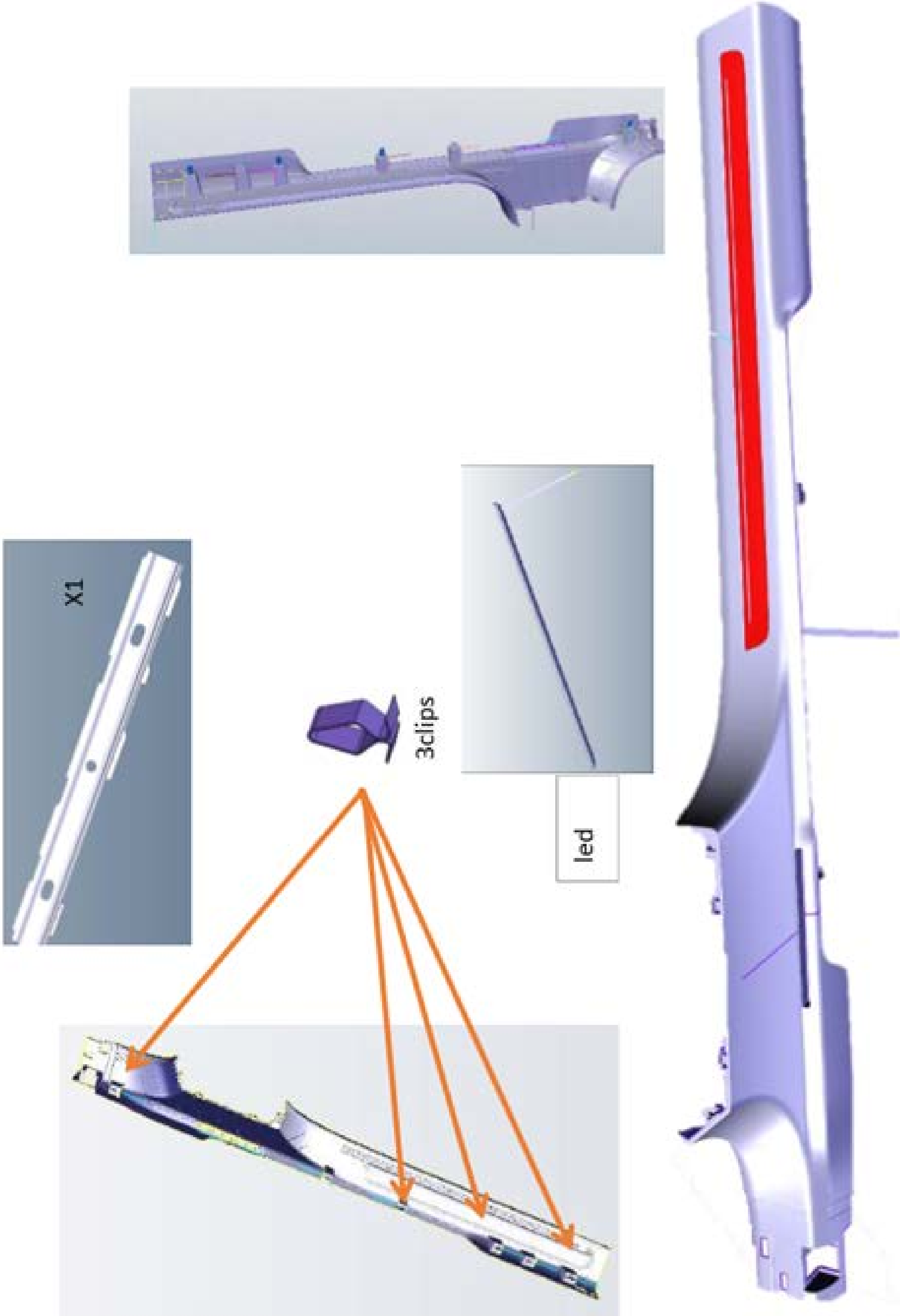


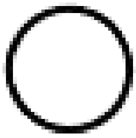
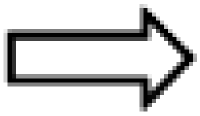
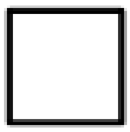
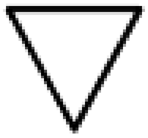
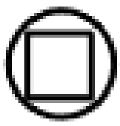
Figure 39 - F-code + Components

4.2 Manufacturing processes involved (Diagram and a brief explanation)

To present the manufacturing process of the product under study, it is necessary to know all the operations, controls, transport or flows and storage of this process. Using the process diagram, it is possible to show all the activities in the process. (Ishiwata, 1991)

The meaning of the symbols on the process diagram can be seen in Table 3.

Table 3 - Symbols of process Diagram (Ishiwata, 1991)

Activity	Symbol	Meaning
Operation Transformation		Change of shape or other characteristics of the material, obtaining semi-finished product or product in the process of manufacturing.
Transport		Change of place of raw material, finished product or semi-finished product
Inspection		Counting and checking materials or comparing products according to the specifications.
warehouse		Defined place to storage, raw material, finished product or semi-finished product and components
Combined Activities		Operation with quality control

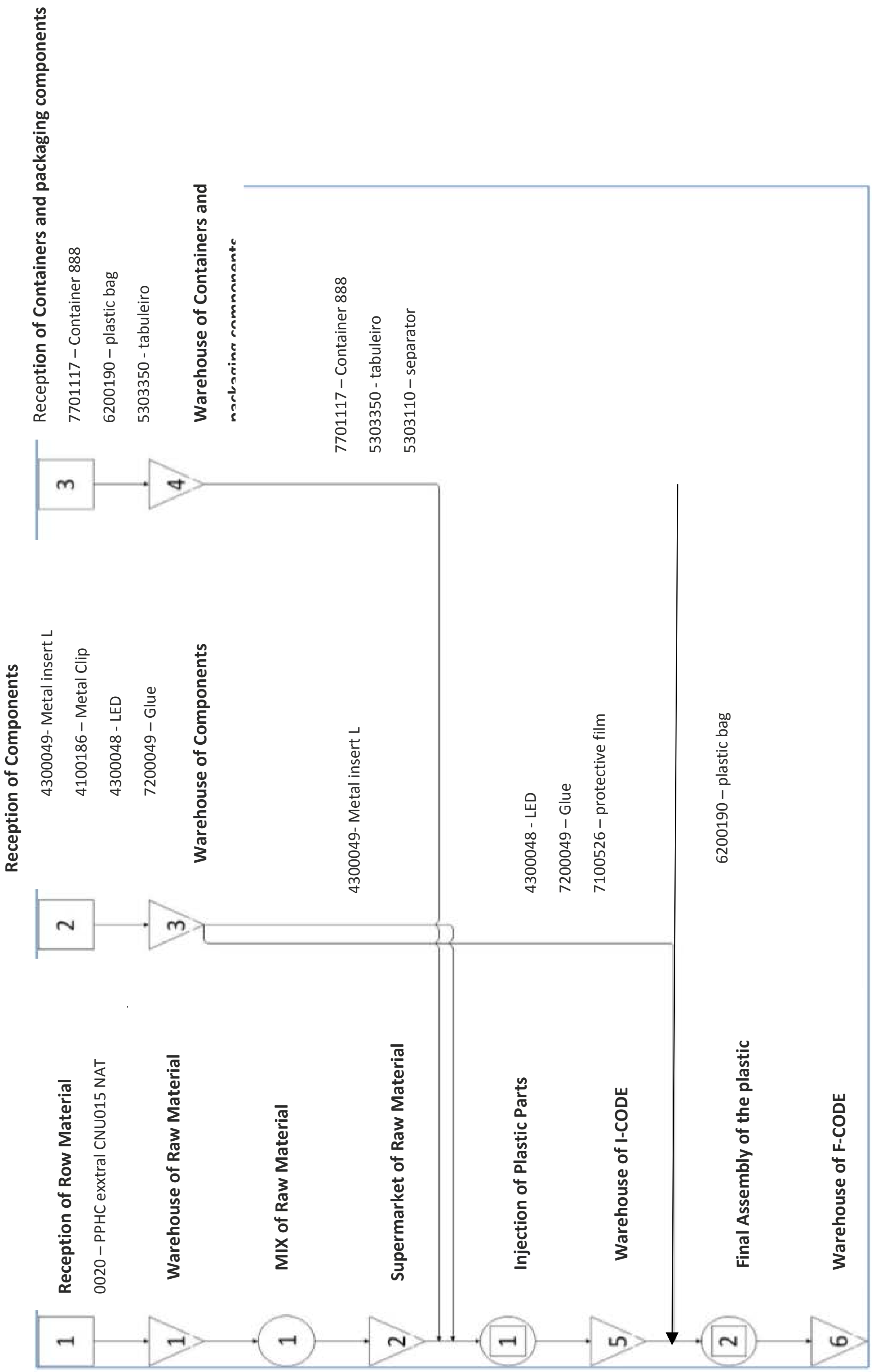


Figure 40 - Process diagram of Einstiegsleiste Stormgrey left side version ONROAD

Following the process diagram it is possible to understand that raw materials, components and packaging components go through an inspection (quality control 1,2,3) and are stored in the respective warehouse (1,3,4).

When it is necessary to produce, the production department sends the information to all the departments using the internal system of the company.

The production department has the responsibility to mix the raw material (operation of transformation 1) and print the production orders, labels, and pull cards. The production department is also responsible to put the mold in the machine and also for the training of the operators with the support of the quality and engineering departments.

The engineering department is responsible for checking the layout, process, devices.

The quality department is responsible for controlling the quality of the part, for checking if the operator is trained properly and if the documentation is in an order and corresponds to the reality.

The logistics department after receiving the pull cards is responsible to bring all the components.

Then the MIX of the raw material goes to the warehouse 2 waiting for the beginning of production.

This process is composed of injection followed by assembly line.

In the injection, each injection produces two parts, one in the right and 1one in the left, and one metal insert and three clips in each part (combined activities 1– transformation and quality control) are being assembled. Then parts are being packed and sent to the I-code warehouse (5).

In the assembly line, there are left and right equipment that work one part each time. Here the LED is glued to the plastic part and protected with a protective film, after it is placed in a plastic bag and packed (combined activities 2– transformation and quality control). From this point, the parts go to the F-code Warehouse (6)

This analysis will focus on the injection and assembly line transformation processes.

4.3 Initial VSM

The initial VSM is in the annex.

The first step in creating a process map is to develop a full understanding of the process from A to Z.

Firstly, both injection and assembly line process was observed. Having a complete understanding of all the activities on and between both processes is possible to do some measurements.

Table 4 - INPUT DATA

Input Data	tool	8341
	machine	EN 1100 III
	demand (cars/month)	14989
	CT injection	55
	Operators	2
	RO (%)	90
	Packaging	VW 888
	Parts/row	8
	Parts/container	64

One of the first measurements to do is the takt time.
Takt time is the maximum amount of time in which a product needs to be produced in order to satisfy customer demand.

$$Takt\ time = \frac{\text{Production Time Available}}{\text{Customer demand}}$$

Production time available = 3 shifts (24 hours)

Customer demand = $\frac{15000\ cars/month}{22\ days/month}$ = 700 cars day

$$Takt\ time = \frac{24\ \times 3600}{700} = 123\ seconds$$

Starting by the injection process, the CT and layout were analysed and all activities were recorded and the times of each activity were measured (mean of 10 times of each activity).

Table 5 - VSM current state

Current Injection			
Production		Nº of Operators	2
		CT (s)	55
		Load of Mach (days)	10,5
		Load of Mach (%)	47,7
		MOD	2,86
Comments			
Operator 1 Re=Li		Operations	Time (s)
	1	Collect part Li	2
	2	Verify part Li	5
	3	Cut flashes	10
	4	Place part Li in base	2
	5	Assemble 3 clips	9
	6	Assemble Metal plate	3
	7	Stamp	1
	8	Place part in container (8/2)	4
	9	Place separator (8/8)	1
	10	Place "Tabuleiro cartao" (16/8)	2
	11	Place foam (2/64)	0,03125
	12	Board	1
		TIME NEEDED	41
		TIME AVAILABLE	55

Process (right side = left side):

The operator from right side collects the part from conveyer and inspect by the quality specifications. If necessary, cut the flashes. Places the part in the base and assemble three clips plus one metal plate followed by the stamp.

After the operator repeats the above activities for another part.

Having finished parts, the operator takes both at the same time and pack them.

8 in 8 parts it is necessary to place a separator and a “tabuleiro”.

When the container is full, 64 parts, there is placed a foam.

1 h in 1 h operator has to write in the TRS board the report of the hour before.

Observations:

- 2 operators (1 for each side) – the activities are the same for each one

-CT = 55 s

- Load = $\frac{n^{\underline{o}}\ of\ parts\ (month) \times CT \times working\ days}{second\ per\ day} = = \frac{15000 \times 55 \times 22}{24 \times 3600}$ = 10.5 days/month

- MOD $= \frac{n^{\underline{o}}\ of\ operators \times numbers\ of\ shifts \times load\ machine(days)}{working\ days/month} = \frac{2 \times 3 \times 10.5}{22} = 2.86\ MOD$

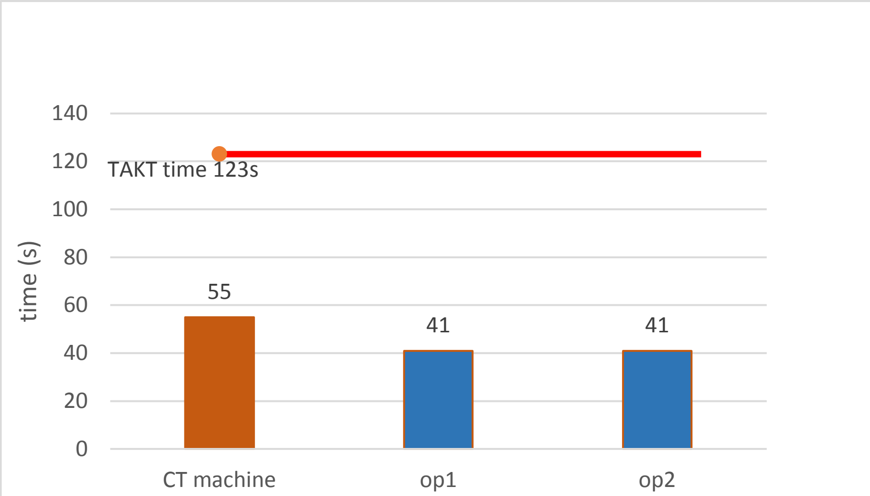


Figure 41 - Time analysis injection

The next image shows the current layout on the principal machine.

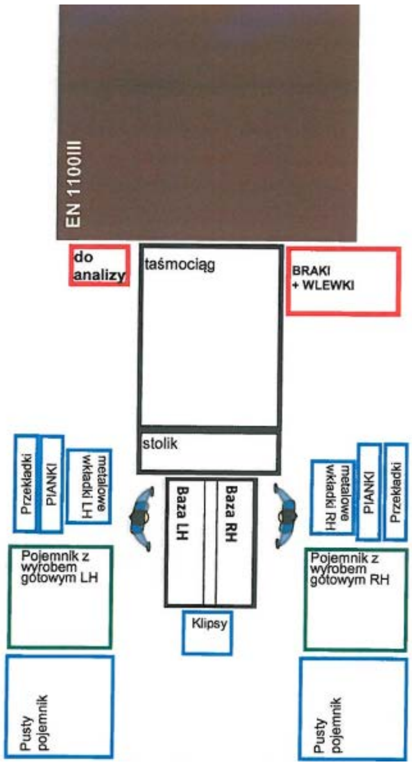


Figure 42 - Current layout injection

Related to the assembly line :

Table 6 - VSM Current state - Assembly line

Current STATE		
Production	Nº of Operators	4
	CT (s)	65
	Working days	11,3
	Load of Mach (%)	51%
	MOD	6,2

Operator 1 Re=Li	Operations	Time (s)
	Collect part1 Li	2
	Inspect part1 Li	5
	Place part1 Li in base	2
	Change LED1 from POS1 to POS2	5
	Inspect LED 2	2
	Place LED2 in POS1	3
	Collect part2 Li	1
	Inspect part2 Li	5
	Stamp	1
	Place Part2 Li in hanger	1
	TOTAL	27

Operator 2 Re=Li	Operations	Time (s)
	Collect part Li	1
	Verify part Li	5
	Place part Li in Validation base + wait	22
	Collect part	1
	Place part Li in base	1
	Put the protection	15
	Stamp	1
	Place in the hanger	1
	Put water	1
	Place part in the plastic bag	4
	Place part in container	4
	Place separator (8/8)	1
	Place "Tabuleiro cartao" (16/8)	2
	TOTAL	59

Process (1st operator right side = 1st operator left side):
The first operator collects the part form the container, proceeds with the inspection. If the Part is OK it is placed in the base, LED1 with glue is placed in POS2. The next step is taking a new LED and insert it and place it in POS1 to receive the glue. The operator takes the PART2 (the part after the being on the device) that was on the hanger, inspect it, stamp it and place it on the buffer for the second operator.
The device has an automatic start after the barrier is free.

Process (2nd operator right side = 2nd operator left side):
The second operator collects the part form the buffer and inspects it. If the part is OK it is placed in the validation device that will check the presence of all components plus if the LED is working properly.
After the validation the operator changes the part for the second base and places the protective film.
The following step is to stamp and hang the part and spray the part with water.
Then we pack the part into a plastic bag and in the container. 8 in 8 parts it is necessary to place a separator and a “tabuleiro”.
When the container is full, 64 parts, there is placed a foam.
Each 1 h of working, the operator needs to write in the TRS board the report of the hour before.

The specifications of both devices can be found in the annex.

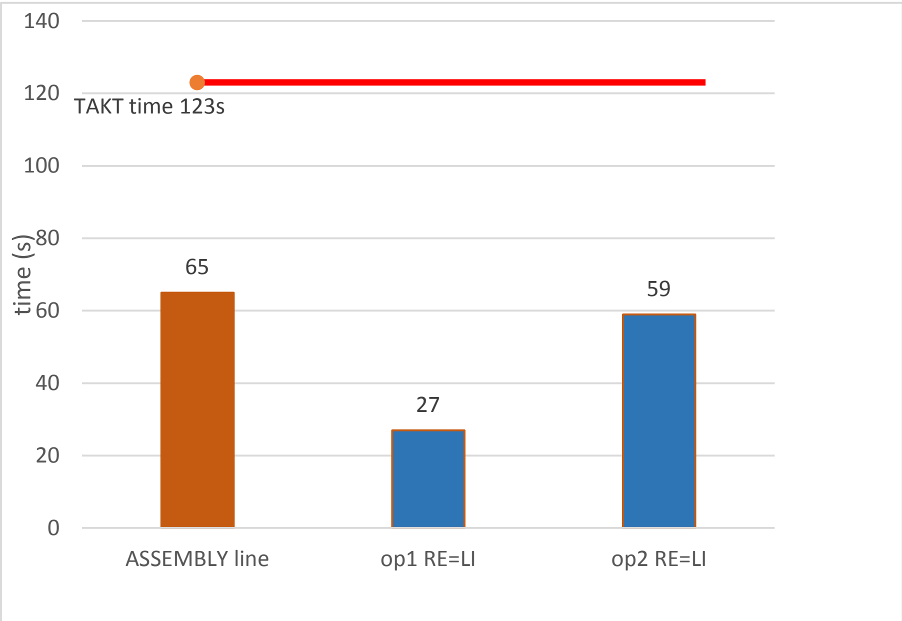
Observations:

- 4 operators (2 for each side)
- CT = 65 s

Load of the machine = $= \frac{15000 \times 65 \times 22}{24 \times 3600}$ = 11.3 days/month

$$\text{MOD} = \frac{4 \times 3 \times 11.3}{22} = 6.2\ MOD$$

Figure 43 - Time analysis of the Assembly Line



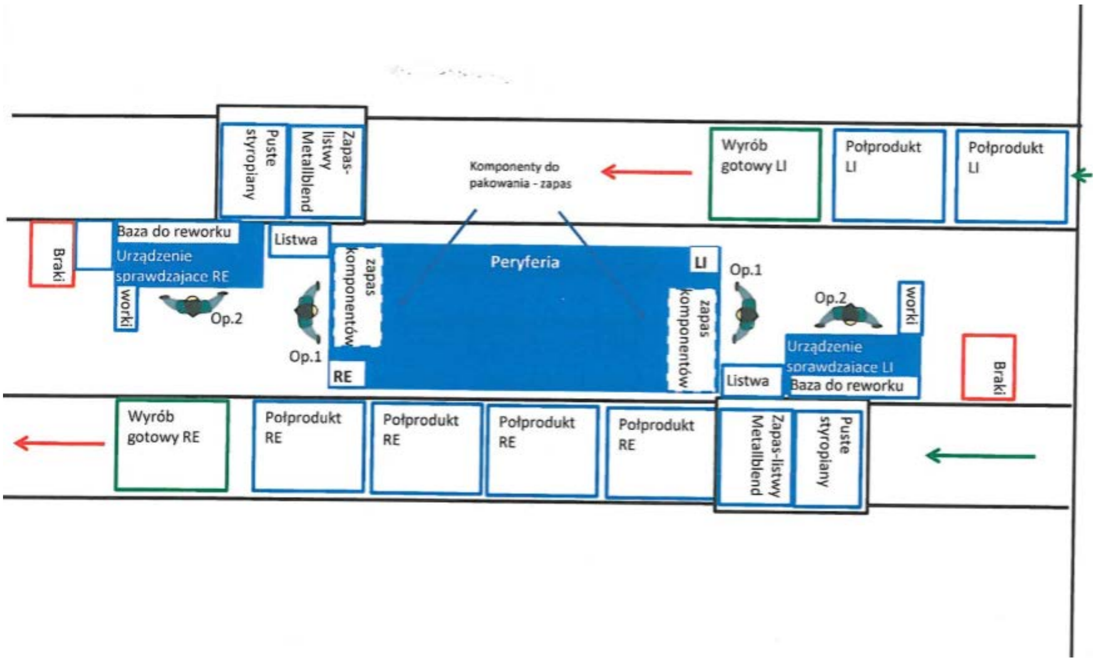


Figure 44 - Current layout assembly line

4.3.1 Detailed problems description

After the first analysis it was evident that there were some problems:

1. Injection

Table 7 - Current VSM injection

Current Injection			
Production		Nº of Operators	2
		CT (s)	55
		Load of Mach (days)	10,5
		Load of Mach (%)	47,7
		MOD	2,86
Comments			
Operator 1 Re=Li		Operations	Time (s)
	1	Collect part Li	2
	2	Verify part Li	5
	3	Cut flashes	10
	4	Place part Li in base	2
	5	Assemble 3 clips	9
	6	Assemble Metal plate	3
	7	Stamp	1
	8	Place part in container (8/2)	4
	9	Place separator (8/8)	1
	10	Place "Tabuleiro cartao" (16/8)	2
	11	Place foam (2/64)	0,03125
	12	Board	1
		TIME NEEDED	41
		TIME AVAILABLE	55

Figure 45 - Flashes on the Part

- Flashes

In the injection, the main problem is the flashes on the part. This is a problem of the deterioration of the mold and must be fixed.

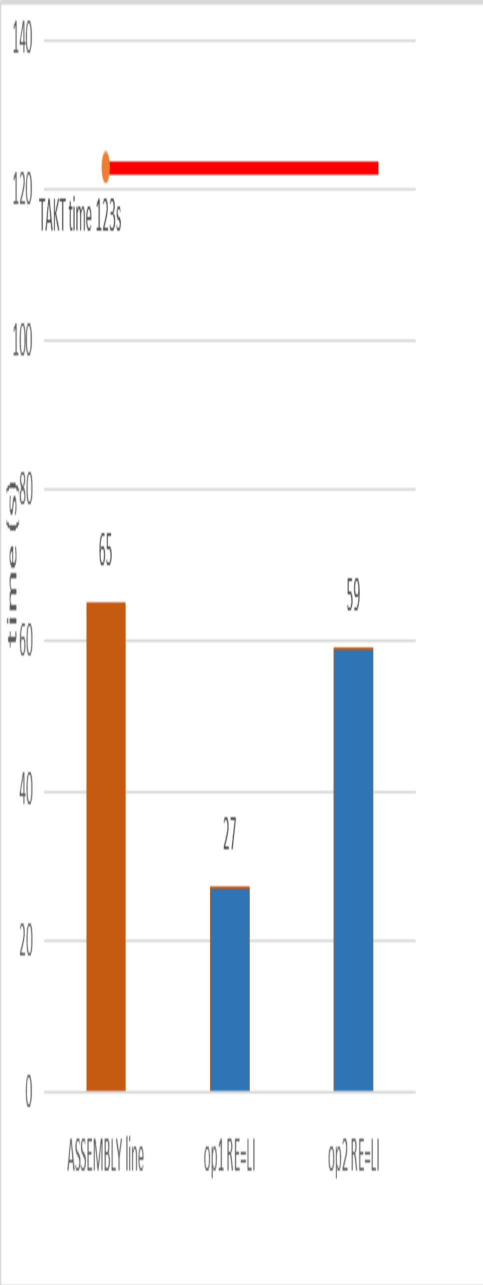
<u>The time lost in this issue is 10 seconds per operator</u>

- Free time

Another problem is the time that the operator is waiting for the machine. Each operator has a dead time of 14 seconds per cycle.

2. Assembly line

Table 8 - Assembly line VSM current state



- Free time

In the assembly line is possible to seed again the same problem about the free time in the 1st operator. In this case the 1st operators (Re1 and LI1) have around 38 s waiting for the device.

Free time waiting for the peripheric device

The 2nd operators (Re2 and Li2) are 22 seconds waiting for the validation of the light device.

- Hard to place the protection of the LED

There is a difficulty related to the glueing of the protective film in the LED

EXTRA problems

By the time of my arrival at the company, there was a big issue related to the assembly line.

The problem in the assembly line was related with the glueing of the LED, there was numerous claims form the client in terms of:

- Unglued LED
- Visible glue on the part

Another big issue is the ramp-up of the quantity in the others. It was known that we will have to produce 30000 parts per month instead of the actual 15000 parts.

4.4 Brainstorming

In order to get some new ideas and new solutions, the group defined bellow started by brainstorming about each problem found.

4.4.1 Group constitution and expertise

Besides me the group responsible to find solutions for the problems mentioned above is:

- Plant manager with more than 10 years of experience in the field (my coordinator)
- Process coordinator with 4 years of experience (the most related to my project):
- Process coordinator with 2 years of experience;
- Quality engineer responsible for this project.

4.4.2 Analysis and action taken regarding the problem - unglued LED

Firstly, and since I have arrived at the company in the middle of an issue related with the glueing of the part at the assembly line, I will address this issue.

- Unglued LED / visible glue on the part

This was a critical problem, which had consumed a lot of resources of the company. There were several claims which caused of the sorting team in the client facilities.

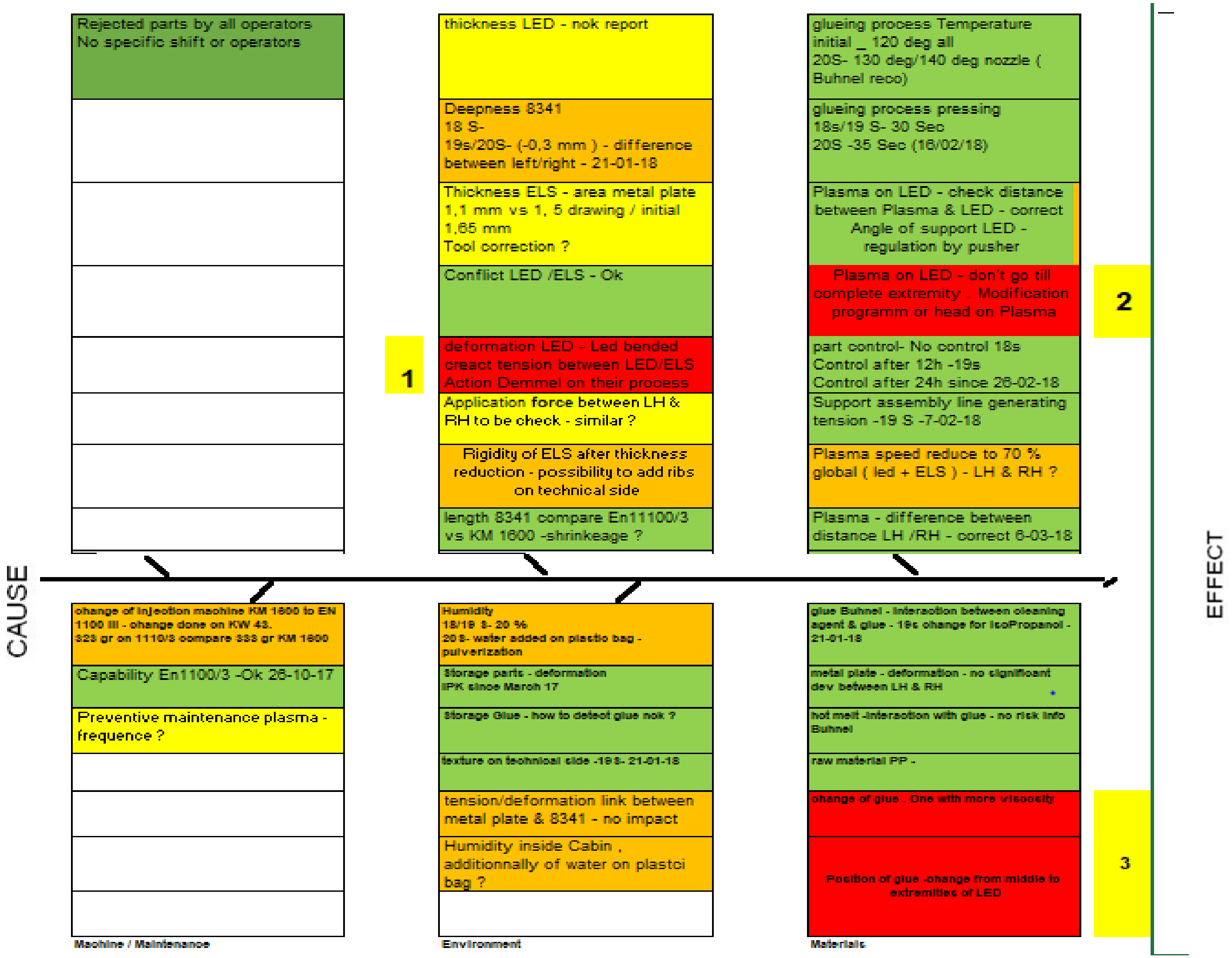
Figure 46 - Unglued LED

To understand the process of the glueing I will explain all the steps

- the part receives a plasma treatment
- the LED with glue receives the same plasma treatment
- the part receives the glue
- the LED is pressed against the part for 35 seconds

To know in which step we were, the following Ishikawa diagram was presented to me, made in a WAR room after receiving the claims.

Table 9 - Ishikawa diagram



In the diagram, there are different colors, these colors define the status and importance of the action, green means that was analysed and closed or doesn't have impact, yellow and orange means that is still waiting for analysis, however orange has more importance. The most critical are in red, these are the ones which have the bigger impact. There are 3 critical causes (red colour) which are:

- 1 critical cause – deformation of the LED

  After taking the LED from the box, there was visible some deformation. The LEDs were bent. This is critical because it can cause bad contact of the LED with the part and an extra tension after glueing the LED to the plastic part. The action made here was to complain to the costumer of the LEDs, to change their process and their packing.

  After our claim to the customer, the LED arrives in better conditions, without being bent, what helped to reduce the tension between the part and the LED.

- 2 critical cause - Plasma on the LED

  The program of the plasma was not properly adjusted to the LED since the plasma was not being applied in all the LED. It was decided to change some coordinates in the program of the Plasma in order to have an application of plasma in all the part and LED homogeneously.

- 3 critical cause - Position of the glue and change of glue

  Due to the fact that after all performed actions internally there was still some incidents in the client facilities, the following action was implemented:
    - Increasing the pressing time 5" in our glueing machine – it is the fastest action that will give the most positive impacts in short term.
    - After some studies, we decided to order a new type of glue with higher adhesive strength. The feedback after the first application was very positive and the new glue is 5 % cheaper, so it was a win/win situation.
    - Another immediate action taken was related with the excess of the glue in the part. We had to change the position and quantity of the glue.

After implementing all these actions there was visible a great improvement in the number of parts rejected both internally and on sorting in the client.

Rejection Decay – Client facilities

Before	around 1,8% - 1,94% LH vs 1,62% RH
After	around 0,5% - 0, 42% LH vs 0,62% RH

Rejection Decay - internally

Before	around 10% - 13 % LH vs 7 % RH
After	around 4% - 5 % LH vs 1,8 % RH

Figure 47 – Rejection decay

4.4.3 Analysis and options regarding VSM

After analysing the VSM, it was considered a few options to change the process from which it was necessary to choose the most efficient one considering the goals: reduction of one operator in injection, keep or lower the LOAD of the machine (critical).

- 1[st] option – Reduction of the CT from 55 s to 50 s

Table 10 – 1º option

Option 1 - Reduce CT from 55s to 50s		
Production	Nº of Operators	2
	CT (s)	50
	Load of Mach (days)	9,5
	Load of Mach (%)	43,4
	MOD	2,60
Comments	Talk with António to see if it is possible to reduce the cycle time of the machine. OK	
Operator 1 Re=Li	**Operations**	**Time (s)**
	Collect part Li	2
	Verify part Li	5
	Cut flashes	10
	Place part Li in base	2
	Assemble 3 clips	9
	Assemble Metal plate	3
	Stamp	1
	Place part in container (8/2)	4
	Place separator (8/8)	1
	Place "Tabuleiro cartao" (16/8)	2
	Place foam (2/64)	0,03125
	Board	1
	TOTAL	41
	TIME AVAILABLE	50

This is a valid option where we will have a lower LOAD in the machine and the time available is higher than the total time used by the operators. In this option, there was no need to fix the mold.

- 2nd option - Reduction of HR (human resources, number of operators) by 50 %

Table 11 - 2º option

Option 2 - Reduce HR in 50%		
Production	Nº of Operators	1
	CT (s)	55
	Load of Mach (days)	10,5
	Load of Mach (%)	47,7
	MOD	1,43
Comments	Fixing the molde we will not have to rework the parts and we will be able to save 20s total	
	NEW LAYOUT	
Operator 1 Re=Li	**Operations**	**Time (s)**
	Collect part Li	2
	Verify part Li	5
	Place part Li in base	2
	Assemble 3 clips	9
	Assemble Metal plate	3
	Stamp	1
	Place parts in container (8/2)	4
	Repeat for Re	26
	Place separator (8"/8)	1
	Place "Tabuleiro cartao" (16"/8)	2
	Place foam (2"/64)	1
	Board	2
	TOTAL	58
	TIME AVAILABLE	55

For this option, it is necessary to fix the mold and create a new layout. However, it will be also needed to have a higher CT, which is not acceptable.

- 3rd option – Reduction of CT (55 s to 50 s) plus Reduction of HR in 50%

Table 12 - 3º Option

Option 3 - Reduce HR in 50% + Reduce CT		
Production	Nº of Operators	1
	CT (s)	50
	Load of Mach (days)	9,5
	Load of Mach (%)	43,4
	MOD	1,30
Comments	Fixing the molde we will not have to rework the parts and we will be able to save 20s total	
	NEW LAYOUT	
	CHANGE CLIPS TO LM	
Operator 1 Re=Li	**Operations**	**Time (s)**
	Collect part Li	2
	Verify part Li	5
	Place part Li in base	2
	Assemble Metal plate	3
	Stamp	1
	Place parts in container (8/2)	4
	repeat for Re	17
	Place separator (8/8)	1
	Place "Tabuleiro cartao" (16/8)	2
	Place foam (2/64)	1
	Board	2
	TOTAL	40
	TIME AVAILABLE	50

To implement this option it is necessary, firstly to fix the tool and secondly to change the process and layout. The change in process is to change the assembly of clips for the assembly line.

The following table shows the new process in the assembly line with the assembly of the clips.

Table 13 - 3º Option - clips in assembly line

	Injection Option3 - Clips in LM	
Production	Nº of Operators	4
	CT (s)	65
	Working days	11,3
	Load of Mach (%)	51%
	MOD	6,2
Comments	While part is in validation we can use that time to put the protection/stamp/place in hanger/put water in other part	
	base to assemble clips	
	another way of protection (save 5s) ???	
Operator 1 Re=Li	Operations	Time (s)
	Collect part1 Li	2
	Inspect part1 Li	5
	Place part1 Li in base	2
	Change LED1 from POS1 to POS2	5
	Inspect LED 2	2
	Place LED2 in POS1	3
	Collect part2 Li	1
	Inspect part2 Li	5
	place part2 in the base	1
	Put clips	9
	Stamp	1
	Place Part2 Li in hanger	1
	TOTAL	37
Operator 2 Re=Li	Operations	Time (s)
	Collect part2 Li	1
	Verify part2 Li	5
	Place part2 Li in Validation base	4
	Put the protection in part3 Li	15
	Stamp part3 Li	1
	Place part3 Li in the hanger	1
	Put water in part3 Li	1
	Bagging part3 Li	4
	Packing part3 Li	4
	Change part2 Li from validation to base	4
	Place separator (8/8)	1
	Place "Tabuleiro cartao" (16/8)	2
	label	1
	trs board	1
	TOTAL	45

With the implementation of the assembly of clips in the assembly line there is no impact in the cycle time of the device or any problem related with the overload of the first operator since initially the 1st operators had more than 30 s free.

Another improvement in the assembly line is the change of the process for the 2nd operator.

The 2nd operator was working 1 part each time however they were waiting for the validation device 20 s.

By changing the process to work in another part while they are waiting for the validation we will save 20 s.

4.5 Planning the actions – implementation of the 3º Option

Regarding the analysis of the VSM and all its options and taking into consideration that we will have to produce 35000 parts per month instead of the actual 15000 parts, the team decide to implement the 3rd option.

Firstly, the tact time

Production time available = 3 shifts (24 hours)

Customer demand = $\frac{35000\ cars/month}{22\ days/month}$ = 1600 cars per day

$$Takt\ time = \frac{24\ \times 3600}{1600} = 54\ seconds$$

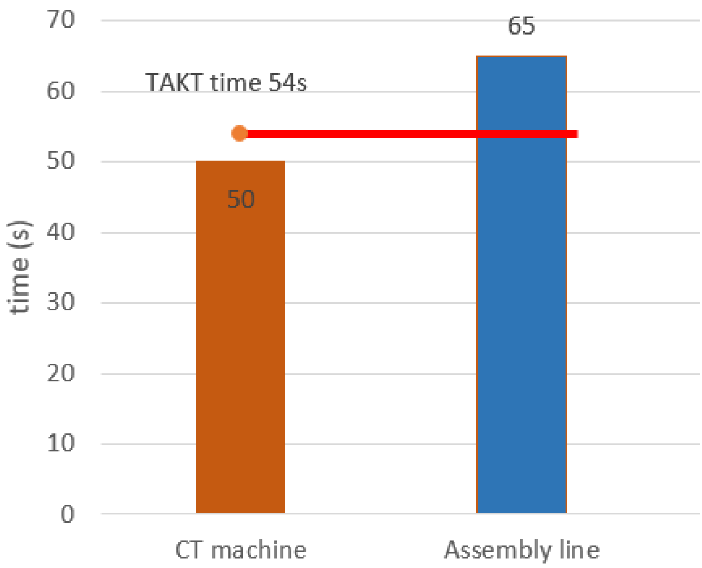


Figure 48 - Time analysis – 3rd option

In the chart, is possible to see that the CT in the assembly line is higher than the takt time after the ramp-up of the orders.

Taking this and all the problems with the glueing of the part into consideration the company decided to order a replica of the same device however with new improvements and corrections based on the lessons learned.

Secondly, and related to the injection process, it is extremely necessary to fix the tool in order to end the flashes and subsequently end with the waste of time to cut them.

There will be a replica of the tool however is still necessary to reduce the CT.

A new layout appropriate for one operator will be needed. Instead of one middle base it is necessary to build 2 separated bases like shown in next figure.

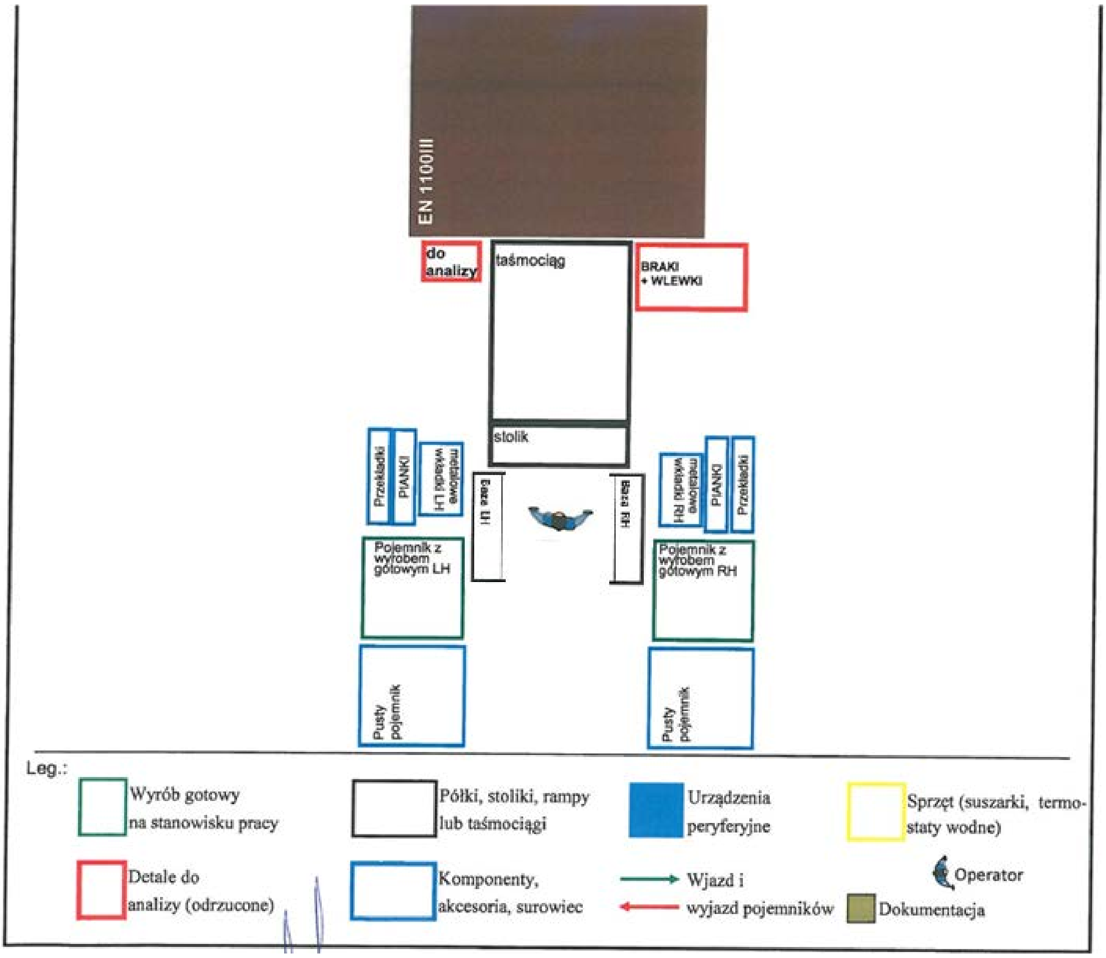


Figure 49 - New lay-out - 1 operator

About the assembly line, it is necessary to change the process. By adding the assembly of clips to the 1st operator, for this person being able to assemble the clips, a small change in the base that they are using in the current process is needed. About the 2nd operator it is necessary to change the process as well following the previous description.

The final state VSM is in annex 7.4.

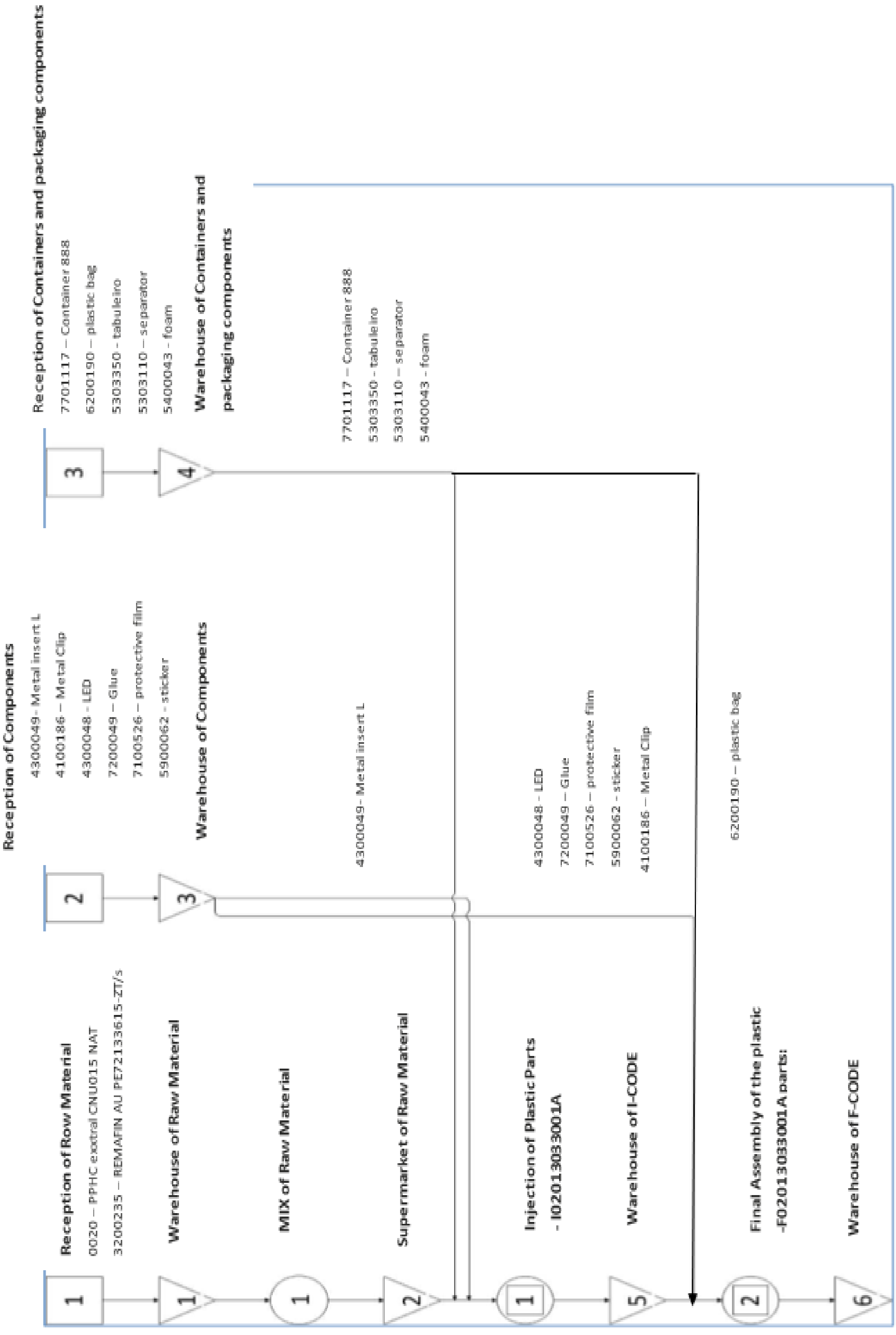


Figure 50 - New Process diagram

4.6 Savings

Every improvement or change in the process have a common goal. The return or saving generated by it.

In this case, there was a change of process and a reduction of HR. Both of these changes will result in a financial saving.

In terms of the injection, the building of the two tables will be done by Simoldes, so no cost associated. Relatively to the reduction of CT and reduction OF HR the savings are presented below.

Table 14 - Savings – 3st option

Current State	$Load\ of\ \text{Machine}=$ $(((680cars/\text{day}\times 55''\times 22days)/(24h\times 3600'')))/(90\%)=\ 10{,}5\ \text{days}$ Labour Hand Needed: $2\ Line\ operatores\times 3shifts\times 10{,}5/22days=3\ MOD$
Future State (3)	$Load\ of\ \text{Machine}=$ $(((680cars/\text{day}\times 50''\times 22days)/(24h\times 3600'')))/(90\%)=\ 9{,}5\ \text{days}$ Labour Hand Needed: $1\ Line\ operatores\times 3shifts\times 9{,}5/22days=\ 1{,}36\ MOD$ **$€\text{Operators}=(3-1{,}36)\times 8h\times 22days\times 10\ months\times €5/h=\ €14432$** **$\text{Machine}=(10{,}5days-9{,}5days)\times 24h\times 10\ months\times €77/h=€18480$** **TOTAL = €32912**

By implement the 3rd option the company will save around 32 000 € per year just by reducing 5 second in CT of the machine and one operator in all the process.

Additionally, after the implementation of the 3rd option in the duplication process (mold plus assembly line), the company savings will rise to 65000 euros

CONCLUSIONS

5 CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

5.1 CONCLUSIONS

The mindset that everyone should have in this kind of work is that all processes in their current state have potential for improvement.

This dissertation aims to the improvement of one process with the help of different tools for the process analysis. The main goal is the profitability of time and the reduction of waste.

In the current process, it was verified that in the injection activity there was a waste of about 25% in terms of time; and in the assembly line, this value was about 55% for the first operator.

After the analysis described in the present work, there was made an improvement that reduces this waste to about 10% in the injection and about 30% in the assembly line.

The implementation of this proposal represents a saving of approximately € 35 000 per year.

5.2 PROPOSALS OF FUTURE WORKS

In the first stage it is necessary to evaluate and validate the improvement plan proposed in this dissertation.

When implementing the improvement actions, monitoring and follow up is essential. Just this way we can follow the PDCA and close the actions and check their effectiveness. It may be necessary to define new actions that can appear during the implementation.

<u>A process is never closed there is always room for improvements.</u>

REFERENCES AND OTHER SOURCES OF INFORMATION

6 REFERENCES AND OTHER SOURCES OF INFORMATION

Ávila, P. A. (2010). *Vertentes da Optimização*. Porto, Portugal: ISEP.

Antoniolli, I. (2017) 'Standardization and optimization of an automotive components production line', *Procedia Manufacturing*. Elsevier B.V.

Barbosa, B. (2017) 'Solving Quality Problems in Tyre Production Preparation Process: A Practical Approach', *Procedia Manufacturing*.

Barbosa, R. C. N., Campilho, R. D. S. G. and Silva, F. J. G. (2018) 'Injection mold design for a plastic component with blowing agent', *Procedia Manufacturing*.

Bhasin, S. (2012) 'Performance of Lean in large organisations', *Journal of Manufacturing Systems*. The Society of Manufacturing Engineers

Büyüközkan, G. and Öztürkcan, D. (2010) 'An integrated analytic approach for Six Sigma project selection', *Expert Systems with Applications*. Elsevier Ltd.

C. Poirier, C. (2003) *The Supply Chain Manager s Problem-solver*. St. Lucie Press.

Carpanzano, E. and Jovane, F. (2007) 'Advanced Automation Solutions for Future Adaptive Factories', *CIRP Annals - Manufacturing Technology*.

Carson, B., M. Alper, M. and Keck, C. (2004) *Quality Management Systems for Assisted Reproductive Technology*. Taylor & Francis.

Chase, Jacobs and Aquilano (2005) 'Facility Layout', *Operations Management for Competitice Advantage*

Chryssolouris, G., Papakostas, N. and Mavrikios, D. (2008) 'A perspective on manufacturing strategy: Produce more with less', *CIRP Journal of Manufacturing Science and Technology*,

Church, J. and Ware, R. (2014) *Industrial organization*, *New York*. McGRAW-HILL.

Coskun, A. (2010) *Quality Management and Six Sigma*.

Costa, T., Silva, F. J. G. and Pinto Ferreira, L. (2017) 'Improve the extrusion process in tire production using Six Sigma methodology', *Procedia Manufacturing*. Elsevier B.V.

Course Technology, I. (2002) *Quality management*.

Dave, S. (2012) 'Le a n T h i n k i n g', *International Journal of Lean Thinking*, Volume 3.

Davis, E. and Spekamn, R. (2003) *The Extended Enterprise*. Peason Educarion.

Demeter, K. and Matyusz, Z. (2011) 'The impact of lean practices on inventory turnover', *International Journal of Production Economics*. Elsevier.

Dencker, K. *et al.* (2007) ‘Proactive assembly systems-realizing the potential of human collaboration with automation’, *IFAC Proceedings Volumes .*

Easton, G. S. and Rosenzweig, E. D. (2012) ‘The role of experience in six sigma project success: An empirical analysis of improvement projects’, *Journal of Operations Management*. Elsevier B.V.

Elkins, D. A., Huang, N. and Alden, J. M. (2004) ‘Agile manufacturing systems in the automotive industry’, *International Journal of Production Economics*.

Eroglu, C. and Hofer, C. (2011) ‘Lean, leaner, too lean? the inventory-performance link revisited’, *Journal of Operations Management*. Elsevier B.V.

Frenkler, D. and Zawistowski, H. (2001) *Hot Runners in Injection Moulds*.

Goodship, V. (2004) ‘Troubleshooting Injection Moulding, Volume 15’.

Goodship, V., Arburg (Firm) and Rapra Technology Limited (2004) *Practical Guide to Injection Moulding Edited by Vannessa Goodship*.

Hines, P. and Rich, N. (1997) *The seven value stream mapping tools*.

Hoyle, D. (2005) ‘Automotive Quality Systems Handbook’, *Automotive Quality Systems Handbook*.

Hoyle, D. (2007) *Quality Management Essentials*. Elsevier B.V.

Hu, S. J. *et al.* (2011) ‘Assembly system design and operations for product variety’, *CIRP Annals - Manufacturing Technology*.

Hunter, S. L. (2001) ‘Ergonomic evaluation of manufacturing system designs’, *Journal of Manufacturing Systems*.

Ishiwata, J. (1997) *E Shop Floor 1: Process Analysis: Productivity Through Process Analysis*. Productivity Press.

J. Jarvinen *et al.* (1998) *PDCA-cycle in implementing design for environment in an R&D unit of Nokia Telecommunication*. Conference Paper.

Jones, P. (2009) *Budgeting, costing and estimating for the injection moulding industry*.

Juran, J. M. and Godfrey, A. B. (1998) *Juran’s Quality Control Handbook*. 5th edn, *McGrawHill*. 5th edn.

Karlberg, B. and Pacey, G. E. (1989) *Flow Injection Analysis: A Practical Guide*.

Kenneth H., R. (2010) *Project Quality Management Why, What, and How*, *Case Studies in Project, Program, and Organizational Project Management*.

Kenneth w. Daily (2003) ‘THE LEAN MANUFACTURING POCKET’. DW.

Liker, J. (2004) *The Toyota Way : 14 Management Principles from the World’s Greatest Manufacturer*. McGRAW-HILL.

Line, L. A. (2007) *Kaizen Assembly: Designing, Constructing, and Managing a Lean Assembly Line June 28, 2006*, *Assembly Automation*.

M. Bryce, D. (2016) *Plastic Injection Molding: Manufacturing Process Fundamentals*. IPLAS.

Melton, T. (2005) 'The benefits of lean manufacturing: What lean thinking has to offer the process industries', *Chemical Engineering Research and Design*, 83(6 A), pp. 662–673. doi: 10.1205/cherd.04351.

Moen R. and Norman, C. (2006) *Evolution of the PDCA Cycle*. Detroit, USA.

Monden, Y. (2011) *Toyota Production System: An Integrated Approach to Just-In-Time*. 4th edn. Productivity Press.

Monks, J. G. (1987) *Administração Da Produção*. São Paulo: McGRAW-HILL.

Neves, P. *et al.* (2018) 'Implementing Lean Tools in the Manufacturing Process of Trimmings Products', *Procedia Manufacturing*.

Noor, N. A., Kasolang, S. and Jaffar, A. (2012) 'Simulation of Integrated Total Quality Management (TQM) with Lean Manufacturing (LM) practices in forming process using Delmia Quest', *Procedia Engineering*.

Norman, L. (2016) *Pratical Guide to Blow Moulding*. Smithers Rapra Technology.

Pande, P. S., Neuman, R. P. and Cavanagh, R. R. (2000) *The Six Sigma Way*. McGRAW-HILL.

Panizzolo, R. (1998) 'Applying the lessons learned from 27 lean manufacturers. The relevance of relationships management', *International Journal of Production Economics*.

Peter,D., M. (2010) *Quality Management Theory and Application*. CRC Press.

Pinto, J. P. (2014) *Pensamento Lean, A filosofia das organizações vencedoras.* 6th edn. Lidel - Zamboni.

Samson Teklehaimanot (2011) *Simulation and Design of a plastic injection Mold*. ARCADA.

Shingo, S. (1990) 'A Study of the Toyota Production System from an Industrial Engineering Viewpoint', *Manufacturing Engineer*.

Silva, M. (2009) *Estudo de Tempos e Métodos - A Medida do Trabalho.* ISEP.

Stanley, M. (1997) 'FUNDAMENTALS OF POLYMER PROCESSING'. McGRAW-HILL.

Warren, M. (1973) ' TPS Manual'.

Warren, M. (2017) '1973 Toyota Production System Manual', 2017, pp. 1–49.

William_M_Feld (2001) *Lean Manufacturing Tools*. CRC Press.

Wilson, L. (2010) *How to Implement Lean Manufacturing*.

Zairi, M. (2015) 'Total Quality Management for Mechanical Engineers', *Mechanical Engineers' Handbook.*

ANNEXES

7 ANNEXES

7.1 Annex1- Current working instruction – injection

7.2 Annex2- Current working instruction – Assembly line

7.3 Annex3- VSM current state

7.4 Annex4- VSM future state

7.5 Annex5- Fimel - Glue equipment - DESCRIÇÃO TÉCNICA

7.6 Annex6- Glue equipment – specifications

7.7 Annex7- Einstiegesleiste detection device