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Reducing Production Disturbances to enhance Quality, Production Performance and Sustainability

A Case Study at Plastteknik AB, Sweden

Master's Thesis in Production Engineering

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Department of Industrial and Material Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

MASTER'S THESIS 2019

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Abstract

This thesis focuses on reducing the production disturbances at Plastteknik AB in order improve the quality of the product along with production performance and sustainability.

With an aim to reduce the production disturbances, we gather both qualitative and quantitative data followed by analyzing the data in search of patterns in disturbances and then suggesting feasible solutions to those problem. Major stakeholders being Plastteknik AB, and their customers.

This report encompasses information regarding the case study using Six Sigma DMAIC method and tools to identify the disturbance and analyzing the root causes. On the other hand, to have feasible solutions and recommendations to overcome the problems associated to have high quality of products. Concluding with presenting the outcomes of this thesis along with suitable solutions and recommendations to the identified problems.

Keywords: Production Disturbance, Quality, DMAIC, Sustainability, Maintenance.

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1
Introduction

This chapter presents the thesis background along with problem description and thesis objectives, following it up with delimitations and research question in the latter section of this chapter.

1.1 Background

Today's productions system is more focused on being resource-efficient to achieve high productivity with flexibility (Jon Bokrantz et al., 2016). Even with a strong commitment to production and maintenance personnel, companies have failed to improve the performance in terms of overall equipment effectiveness (OEE). Which has pressurized the companies to minimize the production disturbances that cost Swedish manufacturing industries billions of Swedish kronor per year (Jon Bokrantz et al., 2016). However, recent technologies and software have made it possible to gather the data from the machines on a regular basis, which can be used to analyze the disturbance pattern.

The companies have carried out various researches in identifying the parameters that affect product quality and production performance. Production disturbance affects overall equipment effectiveness, which directly hampers quality and production performance. Production disturbance has proved to be a major thorn in the production performance which affects quality, decreases productivity, increase product cost and reduces profitability (Jon Bokrantz et al., 2016).

The current project involves analyzing qualitative and quantitative data to find a disturbance pattern which will eventually lead us to the root cause of the quality problem. When further analyzed in-depth could lead us to a suitable and feasible solution. The encountered problems can be analyzed to achieve products of the highest quality.

1.2 Problem Description

Production disturbance has been a major problem in the industries because of which industries are losing both time and money. Production Disturbances can be seen from several different perspectives and can be described with various words, such as disruptions, failures, errors, defects, losses, and waste (Bellgran M et al., 2002). Most of the manufacturing industries emphasize reducing these disturbances in order to reduce the wastage of cost and time, which in turn affects productivity, quality, and efficiency. In order to support this our thesis mainly focuses on identifying the root causes that are responsible for the production disturbances at Plastteknik AB in order to increase the product quality, production performance, and sustainability.

1.3 Objectives

The main objectives of this thesis are to investigate the production disturbances at Plastteknik AB by analyzing the factors responsible for the quality problem, production disturbances and finding suitable solutions for the identified problems.

The thesis also aims to analyze the problem by implementing various qualitative and quantitative analysis methods to assess the overall sustainability impacts of disturbances in production systems.

1.4 Scope and Delimitations

Our focus is on identifying and analyzing the root cause factors that are responsible for the production disturbance which affects the quality of the products. This study is specifically targeted towards two products Product A and Product B which are having a major quality issue at Plastteknik AB as mentioned by the company personnel. In addition, we will be focusing on production disturbances that affect the Quality of the products. Also, we are not going to carry out any destructive or non-destructive testing (NDT) on the products.

1.5 Research Questions

- How does the production disturbances affect the Quality of the product?
- How does information and production flow impact on the production disturbances?
- How do we balance the product quality and overall equipment effectiveness without hampering productivity?
- Why is the role of maintenance important on Overall Equipment Effectiveness(OEE) and product quality?

These set of questions will serve the contents of the methods and results section and are further discussed.

2
Theory

This chapter gives an insight into the industrial background and theoretical background. What is a production disturbance? Formulas involved in measuring production disturbance, and problem-solving method along with the theoretical background to the manufacturing process involved in this case study procedure and techniques that have been used in the thesis work.

2.1 Industrial Background

The case study was conducted in a company which produce plastic parts using injection molding process for various application, which includes packaging and automotive parts. Since the quality standards required in the automotive parts are very high. The lead time to supply the products on time in a fast-paced environment is difficult to manage. Well-established methods and strategies are required to fix the internal problem in a structured way to satisfy the customers.

The reason why we choose the two automotive products is discussed in the further chapter section 5.1.2. From the authors of this case study point of view, when a company works as a tier 1 or tier 2 suppliers. They don't have flexibility to change the product design or design the process according to their own standards. They need to follow certain standards given by their external customers. In this case study if the company needs to make a certain design change in the process they need to follow an Advanced Product Quality Planning (APQP) test which is most common across the automotive industry. Advanced Product Quality Planning (APQP) is a simultaneous process and similar to Design of Six sigma. Once these products have been introduced for production the quality of the products has to be maintained with high standards. Also, the authors in this case study have made the observation about different measuring and database systems which are not interconnected. The necessity of this are explained in section 5.4 research question 3 and chapter 6 section 6.2.

They have an IFS system commonly known as the Enterprise Resource Planning (ERP) software which is basically used for planning and inventory purpose. The data is stored in the company's internal server. A software known as RS production which is commonly known as a Manufacturing Execution System (MES) software. Which is used to measure the production disturbance and to calculate the Overall Equipment Efficiency (OEE) of the production in the shop floor. The data is stored in RS production server. The quality measurements are done using two different equipment's the software used is Rektron AB to measure weight and calculate process capability indices known as process capability (Cp) and process capability index (Cpk). Another one is used is to balance the fan and verify the axial run-out of the fan. These data and the machine process parameter data are stored in the machine database itself. Also, access and usage to the database from other cross-functional departments are very limited. The problems caused by these kinds of unnecessary disturbances can be seen in this case study.

When a quality defect arises in the company there is no structured way of solving it. Some problems are solved on experience-based and some are unknowingly solved when they are trying to solve something else. There is no recorded documents for the solved problems was available. Hence, authors in this case study have explained in detail about different problems faced in this case study. In collection of data and solving the problems that the stakeholders should avoid by implementing certain improvement suggestion made by the authors on chapter 6.

2.2 Production Disturbances

Production disturbances can be defined as reducing a planned or unplanned disruption that disturbs a planned production time. That might affect the ease of a process, effective routine, quality, work conditions, environment, etc. (Ylipää, 2000). On the other hand, there are many other production disturbances that should be eliminated from affecting the ideal state of the production system. For example, the machine failure, human error, the external transportation system, the PLC-program or robot program, planning, tool change, setup time, preventive maintenance, cleaning, staff breaks, output from a machine, shortage of staff, power failure, voltage fluctuations, compressed air, cooling water (Ylipää 2000; Harlin et al. 2002, and the TIME-handbook 2004).

Likewise, there are few other production disturbances that might arise in a production system that will affect the ideal state of the production system. Firstly, scheduling in production can cause a problem (Stoop and Wiers, 1996) where production disturbances can occur due to MRP (Manufacturing Resource Planning). They are classified into three types Production disturbances due to the manufacturing system, due to express orders, due to variances in pre-calculated and actual processing time in the MRP (Manufacturing Resource Planning) system. Secondly, in a case study of 80 companies, (Ylipää et al. 2004) it can be seen in Figure 2.1 that various companies have various thoughts on what a production disturbance is concerned in maintenance and a production function.

There are various terms and perceptions being used across various manufacturing industries. Which have the same meaning but with the difference in the definition of a production disturbance (Ylipää, 2000). Similarly, manufacturing companies have differences in considering the planned stop as a disturbance. Also, there is another dimension of production disturbance with respect to the time. Some disturbances may occur frequently with a shorter duration of time which have a major impact than the ones which occurs occasionally with longer duration of time (Ingemansson,2004).

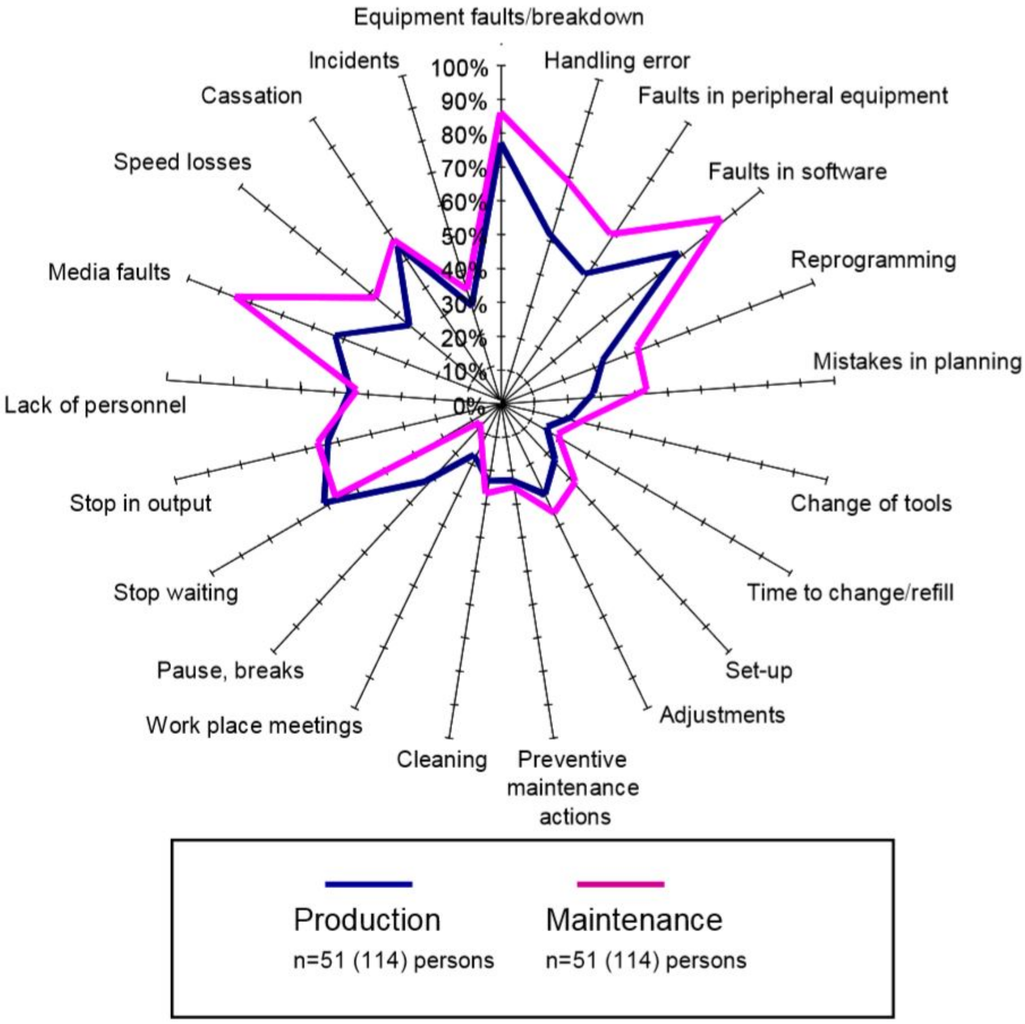

Figure 2.1: *Differences and similarities between the production function and the maintenance function concerning what they regard as production disturbances (Ylipää et al. 2004)*

Since the major ones are easy to identify which also needs general measures than the frequently occurring ones (Ylipää, 2000). Finally, there is no specific standard that can be observed that a production disturbance occurs (Kuivanen,1996). Each manufacturing companies must make their own customized ways of organizing and expressing the production disturbances according to their needs to measure the OEE (Overall Equipment Effectiveness). Also, it is been a major setback in the industries still to choose the right production disturbances. To analyze the problems that are affecting the OEE (Overall Equipment Effectiveness) of the production system (Ingemansson,2004). Hence automated data capturing plays an important role in today's industrial world to capture accurate data and to analyze the problem in an efficient manner (Ingemansson,2004).

In this particular case study, we as authors see a huge set back in the disturbances caused due to production management issues. Which involves the planning and identifying the problems that are affecting the quality of the products. Which contributes to the majority of the total loss in production time.

2.3 Manufacturing Process

In simple terms, a process is defined as *"network of activities that are repeated in time, whose objective is to create value to external and internal customers"* (V. Siva; 2016). A manufacturing process consists of several repetitive steps to achieve a final product before it reaches the end customer as per their requirements. To select a certain manufacturing process various factors are taken into consideration such as production volume, cost, material, design and etc. In this case study, we are referring it to injection molding of plastics which is the most common process used worldwide to produce plastic parts in larger volume.

An injection molding is a repetitive process of filling the mold and later cooling and ejecting the finished product from the mold. As each manufacturing process as certain drawbacks injection molding has also certain drawbacks related to the quality of the product. There are several parameters that have to be taken into consideration in designing the process and the product to keep up the quality of the product. Since the Process, material, machine, and various other factors all together contribute to the product quality. In this case study, we try to find and consider only certain critical process parameters that affect product quality.

2.3.1 Basic concepts and terms in injection molding

The injection molding is a process which is commonly used for mass production. The various steps and basic terms involved in the injection molding process are explained here. Figure 2.2 shows how the pressure varies as the cycle time of the injection molding progresses. Figure 2.3 shows the process steps and the time it consumes in one cycle. The majority of the time is consumed by the cooling process in an injection molding process (Dimla, et al. 2003).

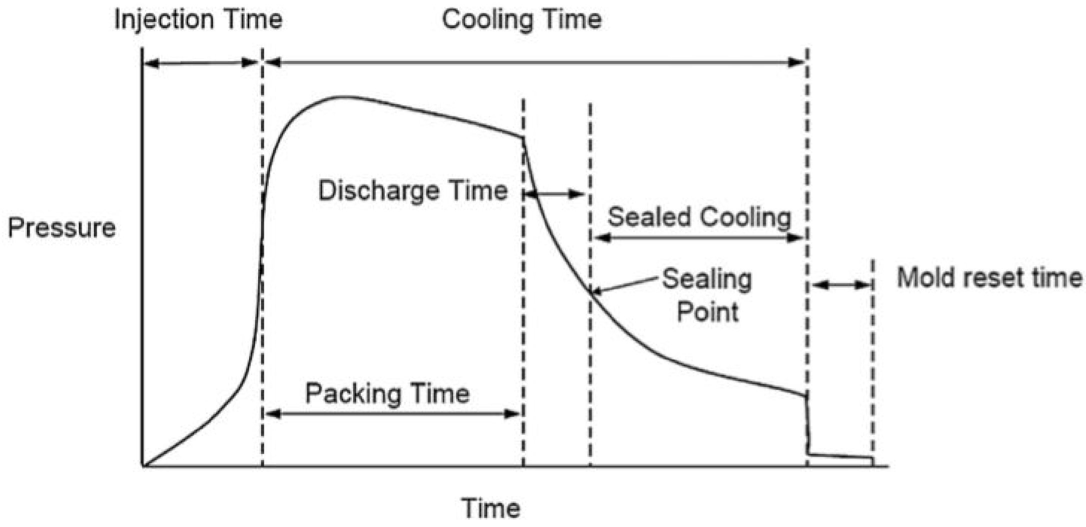

Figure 2.2: *The pressure vs time in an injection molding process (Boothroyd et al. 2011)*

Due to the importance of this case study it is essential to know certain definitions of the machine setting process parameters.

Injection time

The time required to fill certain mould cavity measured in seconds (Whelan, 1982).

$$t = \frac{((d_w.p_r)/(p_f r))^3}{8((T_x - T_m)/(T_c - T_m))^3} \tag{2.1}$$

Bown, 1979 suggested the equation 2.1 to calculate the maximum injection speed at which it can be injected. where t = filling time in seconds, d_w = minimum wall thickness of the moulding in mm, P_r = maximum flow path in mm, $P_f r$ = flow path : wall thickness ratio, T_x = heat distortion temperature in °C, T_m = mould temperature in °C and T_c = maximum cylinder temperature.

Mould closed time

The total time the mould is kept closed until the cooling of the product is finished (Whelan, 1982).

Mould open time

This is total time when the mould face starts to separate from each until the next cycle begins (Whelan, 1982).

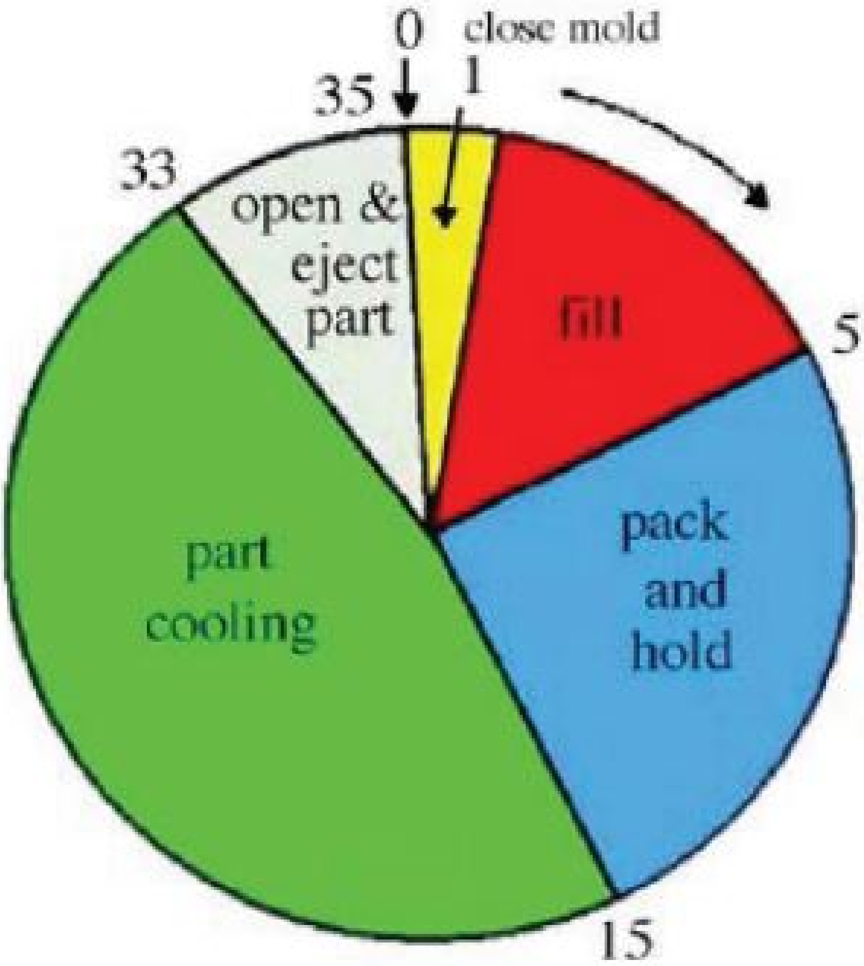

Figure 2.3: *The classification of the cycle time in injection moulding (Dimla, et al. 2003)*

Cooling Time

It's the majority of the time in the total cycle time that is required to cool the part inside the mould (Whelan, 1982).

Cycle time

It is the total sum of the the mould closing time and the opening time (Whelan, 1982).

Mass Pillow cushion

It is to make sure that the pressure is completely transferred to the melt present in the injection cavity and to make sure we have good packing and holding pressure (Whelan, 1982).

Dosing or metering time

Its the time required by the screw to fill the mould and reach the switch over-pressure position during the moulding cycle (Sina, 2003) .

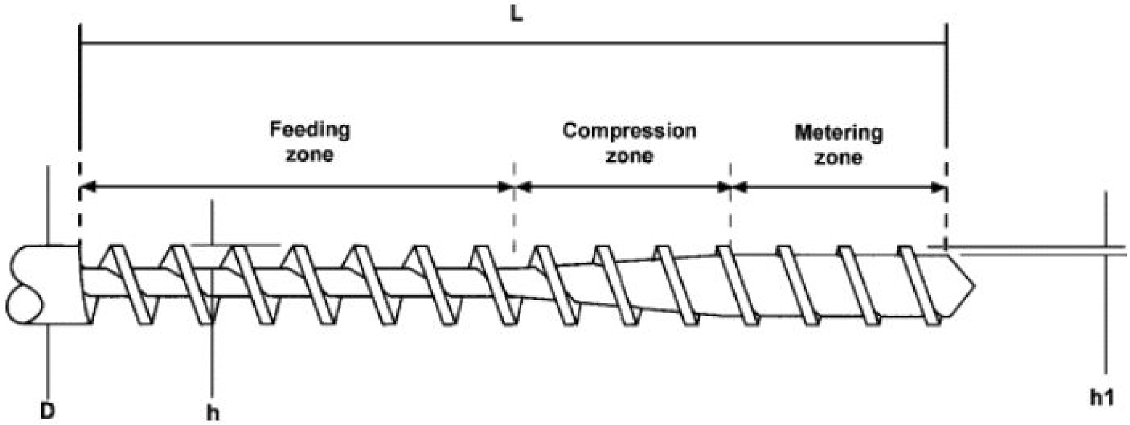

Figure 2.4: *The different screw positions (Sina, 2003)*

Switch over pressure

It is the point at which the pressure switches from filling phase to the packing or holding pressure (Whelan, 1982).

Lock force or the clamping pressure

It is also known as the clamping force the force required to help the mold from not opening (Whelan, 1982). If the force is not sufficient it leads to flash in the edges of the part.

2.3.2 Detailed Injection molding procedure

The process steps are as follows and as shown in figure 2.5
Step 1: The raw material is dried at a certain temperature using hot air blowers for 3 to 5 hours. A humidity test is made to make sure the material is dried enough to use it for manufacturing. Then the raw material containers are connected to the pipes to transfer the material to a hopper in the injection molding machine. This cycle is repeated each time before the start of a new batch in production and when a new container of raw material has to be connected to the pipes for manufacturing.

Step 2: In this step two process happens simultaneously the material from the hopper is fed to the barrel and the movable plate in the mold starts to close.

Step 3: The material is melted to a certain desired temperature in the barrel using heaters.

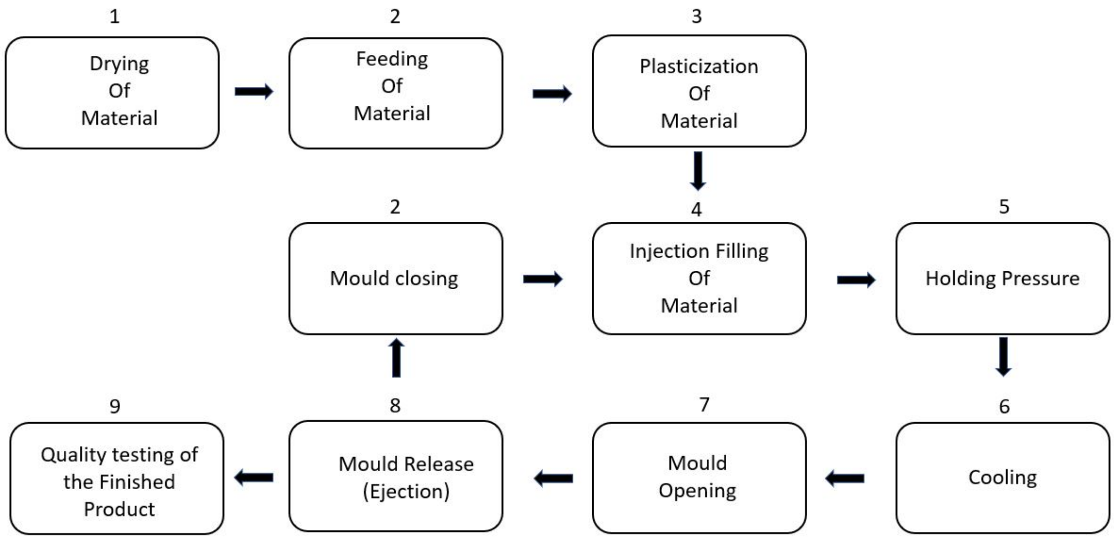

Figure 2.5: *The detailed injection moulding process (ecomolding)*

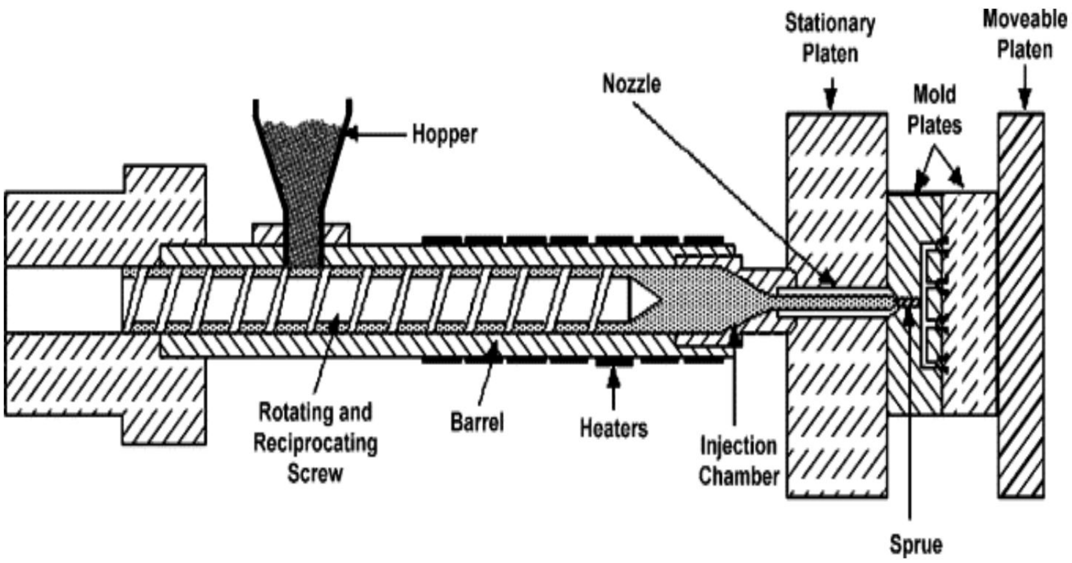

Figure 2.6: *The injection molding mechanism unit. (Sina, 2003)*

Step 4: After the mold has been completely closed and the melted material reaches a certain set value in the injection chamber the melt is injected into the mold at a certain pressure and a set injection time via the injection nozzle.

Step 5: The mold is tightly locked at a certain set holding pressure to avoid flash and excess shrinkage of the material to avoid certain defects.

Step 6: The cooling of the product starts immediately after the melt is injected completely to the mold. water is used as a coolant and there are cooling chambers inside the mold to cool the product.

Step 7: The movable plate in the mold starts to open.

Step 8: The mold ejects the product with the help of the ejector pin in the mold and the cycle repeats from step 2.

Step 9: In this case study quality checks are made in the different procedures. For product A quality checks are made for each individual using a balancing machine to find an axial run-out and imbalance in the product. If the employees find any product out of the desired tolerance limit. They have to rework using clips to balance and have the quality of the product certified. To have both axial run-out and imbalance within the required tolerance limit.

On the other hand, for the product B, it's simple visual inspection from a human eye if they find a defected part they have to just scrap with no rework process involved. Eventually, for both the products they pick random samples in a batch of products to check the weight of the product and coefficient of performance is measured to see the stability of the process.

2.4 Quality management

Every organization uses different tools in order to improve their quality of products and process. There are different quality principles, methodologies, and tools used across the manufacturing according to their requirements for improvements. Each tool differs from their approach and the type of data required to hence it's important to have complete knowledge of each tool (Larsson and Sagar, 2014). It clearly defines the methodologies and tools shown in figure 2.7 (Siva, 2017). Initially, a particular methodology is chosen that suits the organization principles and particular tools are chosen to visualize them.

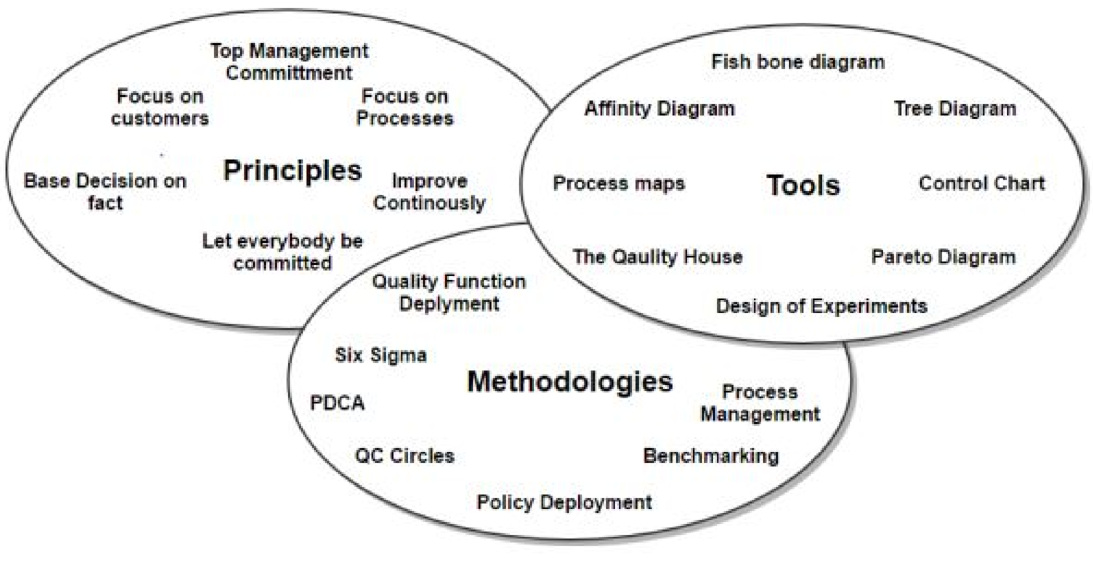

Figure 2.7: *Quality Management, adapted from Hellsten et al.(Siva, 2017)*

Quality aspect can be achieved by predicting the disturbances, improving and controlling to have a stable process in an organization (Madu, 1998). Quality plays an important role in any organization to achieve profits (Siva, 2017).
Some important quality defects that we come across in this case study are explained below.

Burn marks

Air or other gases gets accumulated or trapped inside the mold it leads to an increase in temperature and burning of the plastic (Vyacheslav, 2018).

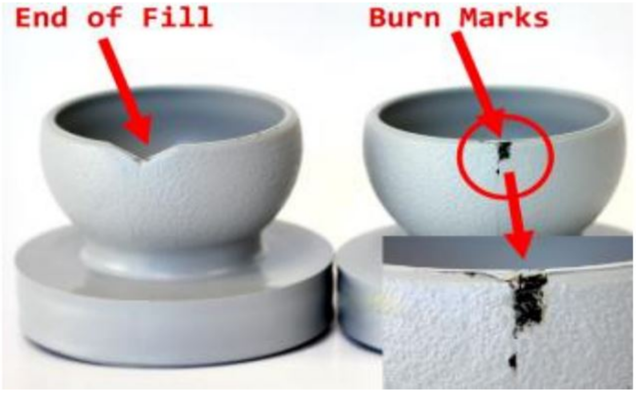

Figure 2.8: *Burn mark (Vyacheslav, 2018)*

Angel's Hair (Flash)

It's is a small hair-like structure that forms at the edges or where the vents and part ejector is located in the mold. Sometimes it's not visible but when the holding pressure is insufficient in keeping the mold closed its very clearly visible to see around the edges and around the treads (Vyacheslav, 2018).

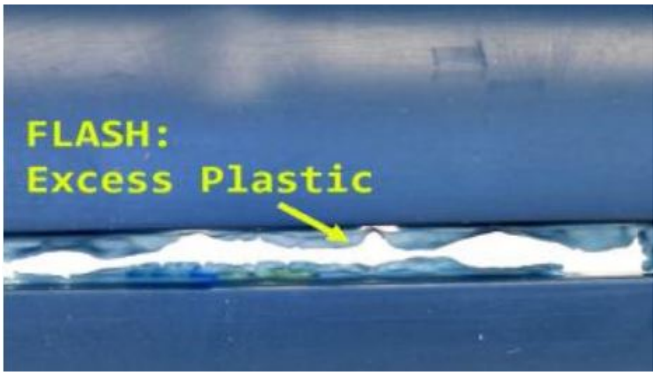

Figure 2.9: *Flash.(Vyacheslav, 2018)*

Cracks

These type of defects occur when there is insufficient temperature maintained in the mold or with a faster cooling rate or uneven shrinkage of the part (Vyacheslav, 2018).

Axial run-out and Imbalance

This two defect occurs mainly due to uneven distribution of the weight in the part, due to the warpage of the part and differential cooling rate. When there is nonuniform shrinkage in the part it leads to axial run-out (Vyacheslav, 2018).

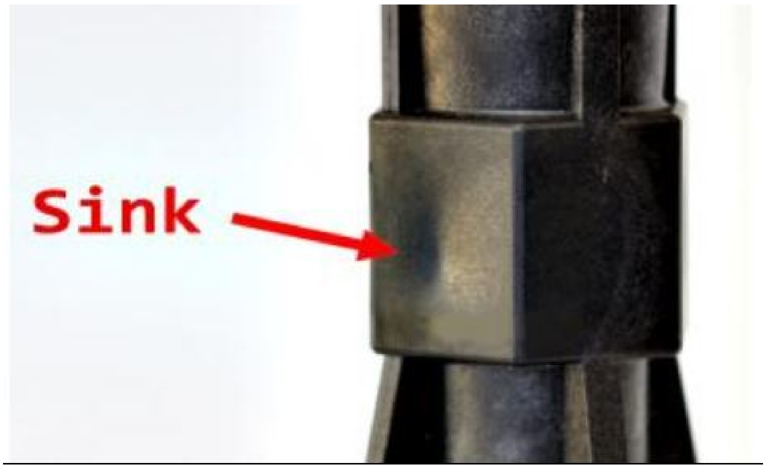

Figure 2.10: *Shrinkage.(Vyacheslav, 2018)*

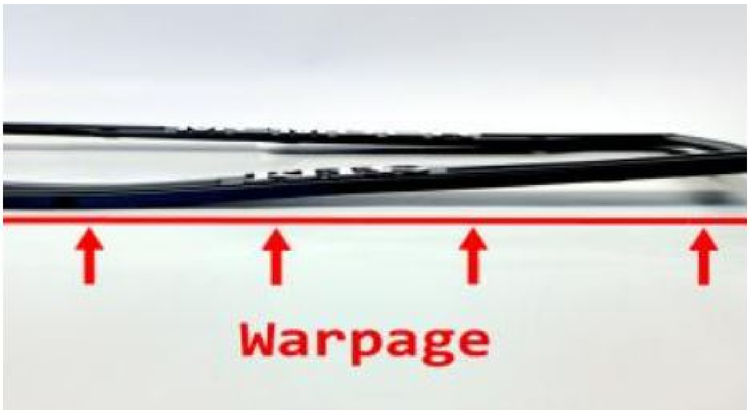

Figure 2.11: *Warpage.(Vyacheslav, 2018)*

2.5 Formulas used

2.5.1 OEE (Overall Equipment Effectiveness)

Originally OEE (Overall Equipment Effectiveness) was industrialized to measure the effects due to PD (Production Disturbances) (Nakajima, 1988; Prickett, 1999) which is been developed from the TPM (Total Productive Maintenance) concept which is as shown equation 2.2. This measurement is best suitable for both fully automatic and semiautomatic manufacturing systems (Ingemansson,2004). The formula has been defined based on this particular case study from the authors and figure 2.12 shows different relationship with each factor.

$$OEE \; = Availability \times Performance \times Quality \tag{2.2}$$

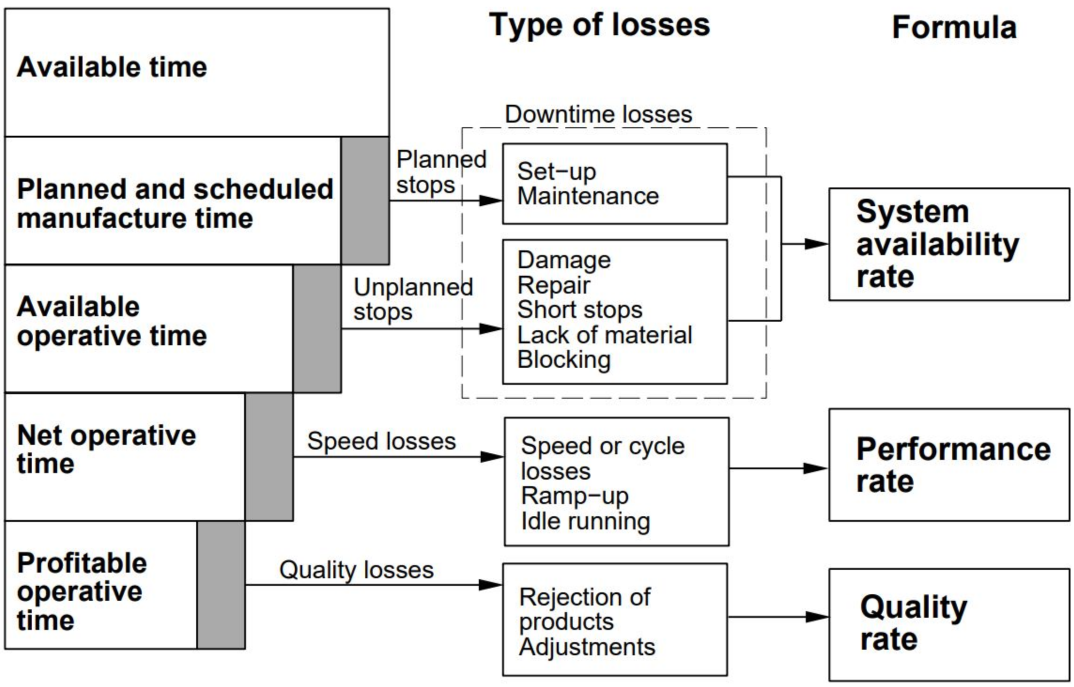

Figure 2.12: *The components of the OEE (Overall Equipment Effectiveness) formula, based on Nakajima (1988), Prickett (1999),Ingemansson (2004).*

$$Availability = \frac{Available\ time - Down\ time}{Available\ time} \tag{2.3}$$

$$Performance = \frac{Theoretical\ cycle\ time \times Produced\ Quantity}{Actual\ time} \tag{2.4}$$

$$Quality = \frac{Produced\ Quantity - Defective\ Quantity}{Produced\ Quantity} \tag{2.5}$$

The system availability shown in the equation 2.3 is one of the main key components in OEE calculation. The downtime indicates the amount of time the machine was affected due to production disturbances. The time required to fix each production disturbances depends on the severity of the disturbance that has caused the process from being stable (Ingemansson,2004). The main production disturbance that affects the quality of the product is more focused in this case study.

The performance of the machine is calculated using the equation 2.4 which is an important factor that affects the quality of the product in this case study. There are various process parameters that affect the quality of the product which is calculated using statistical formulas explained in the section 2.5.2. If the process is not stable it leads to a lot of various problems that are explained in the further chapters. The performance instability affects the theoretical cycle times directly or indirectly and also affects the OEE (Ingemansson,2004).

The quality rate is calculated using the equation 2.5 and a modified equation used in this case study is as shown in equation 4.1. How the production disturbance affect the quality of the product to what percentage in terms of correlation coefficient using the equation 2.9 for total counts and total stop time in hours are also calculated using the equation. Quality is the most important parameter aspect which is considered throughout this master thesis

2.5.2 Statistical formulas

In today's world, many manufacturing industries are trying to control there process using a data-driven approach for decision making or optimizing the process. One such method of controlling the process is SPC (Statistical Process Control) the descriptive statistical formulas and analysis used in this case study are defined bellow. In this topic, the population is referred to an entire data set (Krishnamoorthi, et al 2012).

2.5.2.1 Descriptive statistics

Mean (μ)

Is denoted by the symbol μ which is also known as the average of the entire population represented by the formula in the equation 2.6 (Krishnamoorthi, et al 2012).

$$\mu = \frac{\sum x}{N} \tag{2.6}$$

Where
$\sum \mathbf{x}$ is the total sum of the entire population.
N is the number of counts in the entire population.

Variance (σ^2)

It's a measure between each value from the mean in the entire population. Basically, it can be defined as a summation of, the square of the difference between a random variable from the mean of the entire population divided by the total number of counts in the population. Which is as shown in the equation 2.7 (Krishnamoorthi, et al 2012).

$$\sigma^{\mathbf{2}} = \frac{\sum(x-\mu)^2}{N} \tag{2.7}$$

Where
x is the individual value of the population.

Standard deviation (σ)

It can be simply defined as the square root of variance which is as shown in the equation 2.8. It's a measure in a population and how far the data is spread out from the target or mean of the population. If the value of the standard deviation is low that indicates the population is close to the target. If the standard deviation value is high then it indicates the population is widely spread from the target (Krishnamoorthi, et al 2012).

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{N}} \tag{2.8}$$

2.5.2.2 Correlation analysis (Coefficient of correlation)

It's a method to find a linear relationship between two continuous variables which can also be defined as shown in the equation 2.9. Figure 2.13 indicates a graphical representation of two linearly correlated variables. When the variation is difficult to analyze or make a conclusive decision on the interdependence of two continuous variables using graphical methods (scatter plots) they can be calculated using the equation 2.9 (Krishnamoorthi, et al 2012). In excel it can be directly calculated using advanced data analysis tool.

$$\mathbf{r_{xy}} = \frac{\sum(x-\mu_x)(y-\mu_y)}{\sqrt{\sum(x-\mu_x)^2 \sum.(y-\mu_y)^2}} \tag{2.9}$$

Where
x and y are two independent continuous variables.
$\mu_{\mathbf{x}}, \mu_{\mathbf{y}}$ are mean of x and y in the population respectively.

Positively correlated means when there is an increase in an input variable there is an increase in an output variable simultaneously. Similarly, this also holds good in negatively correlated cases when there is an increase in input simultaneously we have decrease in output. When there is no variation in the output when an input is increased it is said to be no correlation. When $\mathbf{r}_{xy}$ is equal to +1 it's said to be positively correlated. Similarly, when it's equal to -1 it's said to be negatively correlated and when it's equal to 0 it does not have any correlation (Krishnamoorthi et al 2012).

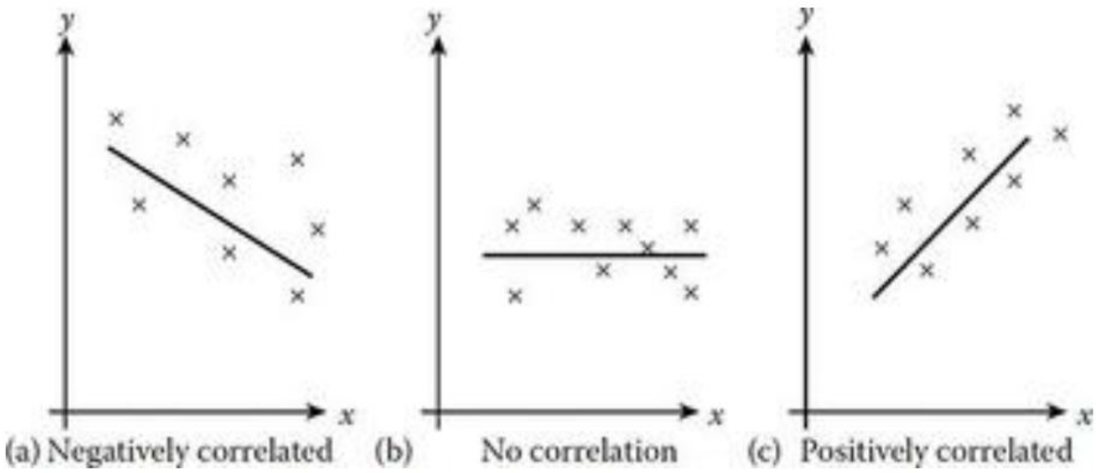

Figure 2.13: *The figure shows graphical indication for different correlations. (Krishnamoorthi, et al 2012)*

2.5.2.3 Regression analysis

Is a mathematical approach to predict or study how an output variable changes with a single independent input variable or multiple independent input variables affecting the output. A simple linear regression equation is represented as shown in the equation 2.10. Where Y is the resultant variable and X is the independent variable in terms of regression language. Similarly, we try to establish a relationship between the independent variable and the resultant variable. We try to fit a straight line where a and b are the slope parameter of the line for a given set of (x,y) Population which is as shown in the equation. 2.10 (Krishnamoorthi et al 2012). For example why we use regression analysis can be explained in simple example if you want to predict at what distance a car stops when brakes are applied to the car traveling at certain speed. Here the speed is the input and the stopping distance is the output. You collect some sample examples of both the speed and the stooping distance of the car and try to build a suitable regression model and predict the values based on the model.

$$Y = a + bX \tag{2.10}$$

where

$$\mathbf{a} = \frac{(\sum \mathbf{Y})(\sum \mathbf{X^2}) - (\sum \mathbf{X})(\sum \mathbf{XY})}{\mathbf{n}(\sum \mathbf{X^2}) - (\sum \mathbf{X})^2}$$

$$\mathbf{b} = \frac{\mathbf{n}(\sum \mathbf{XY}) - (\sum \mathbf{X})(\sum \mathbf{Y})}{\mathbf{n}(\sum \mathbf{X^2}) - (\sum \mathbf{X})^2}$$

Interpretation of regression results from Excel

In this section how to interpret some important regression results from the excel are explained. The explained regression model is chosen for a confidence interval of 95 percent. The numbers marked inside in the table 2.14 will indicate what these values stands for. Where

1) Multiple R represents the coefficient of correlation for the speed and the stooping distance of the car .

2) R square represents the coefficient of determination and also explains the percentage the values are closer to the mean and to what percentage of values this regression model explains.

3) Adjusted R square this value is mainly used in multiple regression analysis instead of the R square. (Krishnamoorthi et al 2012)

4) Observations which is equal to N the number of counts or sample data collected from the population.

5) Intercept which is equal to a in the equation 2.10. (Y=a+bX)

6) Coefficient for the x variable which is equal to b in the equation 2.10.(Y=a+bX)

The modeled equation for this population is represented as

$$Y = -6.37 + 1.15X \tag{2.11}$$

7) The significance F value represents where the selected sample is significant that can we predict the out variable for the selected input variable using the model equation. The significance value should be low as possible if the significance value is higher than 0.05 then it indicates there is some problem in the selected data and not a good model to predict the output variable.

8) The P-Value indicates, the sample chosen has occurred randomly or there is some kind of default that the chosen sample is randomly selected.

Regression Statistics								
1) Multiple R	0.9							
2) R Square	0.81							
3) Adjusted R Square	0.81							
Standard Error	0.010							
4)Observations	706							
ANOVA	Zoeff VS	ZEve [s]						
	df	SS	MS	F	7) Significance F			
Regression	1	0.35	0.35	3156.83	2.3E-262			
Residual	704	0.078	0.00011					
Total	705	0.42						
	Coefficients	Standard Error	t Stat	8) P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
5) Intercept	-6.37	0.13	-46.27	1.1E-215	-6.64	-6.1	-6.64	-6.1
6) ZOeff [s]	1.15	0.02	56.18	2.3E-262	1.11	1.19	1.11	1.19

Figure 2.14: *An example how regression results look in excel*

3

Methods

In this chapter methodology used in this thesis work has been explained in detail. The research strategy and necessary of using certain methods in collecting data and analyzing the data. The conceptual framework to solve the quality-related problem is presented and explained in detail to have a systematic approach to analyze the data and find the root cause of the problem. Finally, the quality of the research with ethics is disused to bring validity and reliability to the case study conducted.

3.1 Research strategy and design

A research strategy can be explained in a simple way. Where there are mainly two types of research qualitative and quantitative research (Bryman and Bell 2011) with respect to business research. There are basically three conditions according to (Yin; 2003) *the research question type, what control does the investigator have on the event, how it behaves and the degree of focus on the historical events.*

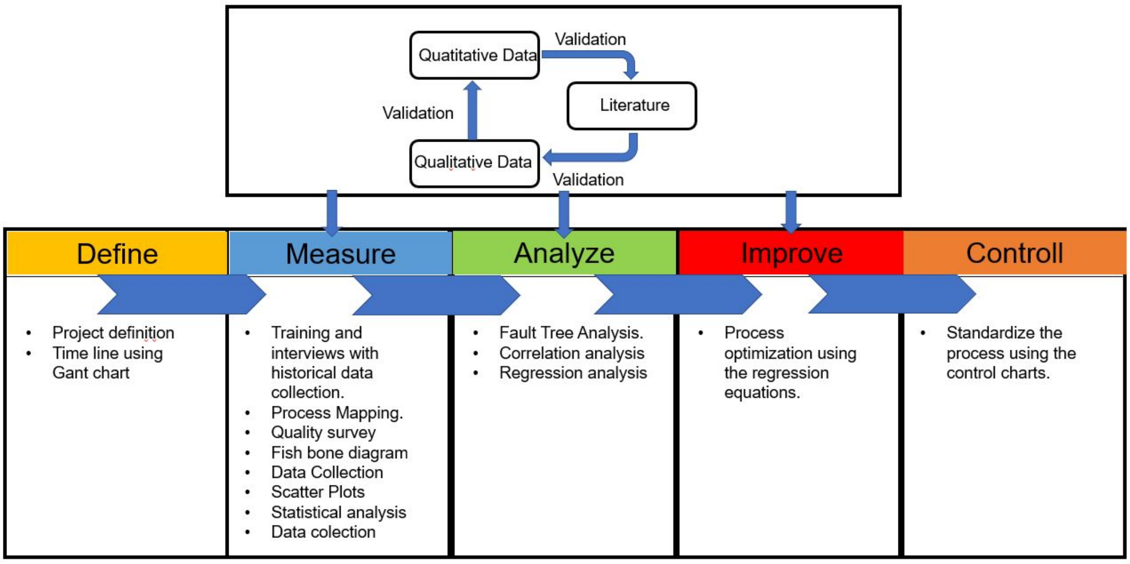

Figure 3.1: *The figure shows the research design and different tools used in the different phases.*

The research strategy that is chosen is a case study research strategy, out of many other strategies, unlike other research strategies this research strategy also has some pre-specified procedures (Yin; 2003). According to Yin (2003), the three conditions that should satisfy in a case study research is the research remark question will be *"how and why"*. There is no required control over the behavioral events, but focus on contemporary events is required. In combination with the case study research strategy lean six-sigma approach, tools and strategies were considered by the authors to design the research method in finding the root cause of the problem. Figure 3.1 shows a conceptual design used to solve the quality-related problems in this case study with the steps or tools involved in each phase, order wise.

3.2 Methodology

Lean six-sigma is a data-driven continuous improvements process for any organization to achieve any desired target or goal (R.Shankar; 2009). It is one of the best methods according to research case study conducted by Mrs. M.S.Lande and Dr.R.L.Shrivastava (Lande et.al; 2016) to solve quality-related problems conducted in small and medium-sized enterprises. It consists of a continuous improvement process called DMAIC where it stands for Define, Measure, Analyze, Improve, and Control. Which consists of various tools that can be used in different phases to find the root cause of a problem. As well as to have a standardized continuous improvement process to stay competitive in today's industrial world.

3.2.1 Define Phase

In the define phase, the problem must be clearly stated and discussed with all the stakeholders involved in the process (R.Shankar; 2009). This phase is the most important for all the stakeholders to understand the complete process. By just walking in the factory to understand the problem. Then the objectives, deliverable, the scope, limitation with the project time-line was proposed on a gantt chart. The define phase in DMAIC projects is used to plan the entire project and certain changes were made through the entire project phase.

3.2.2 Measure Phase

This phase guarantees the stakeholders for a better understanding of the process steps involved in the case study that was conducted. This phase is mainly initiated with the help of the historical data collection which can be later used to see the potential of the improvised process in the later phase (R.Shankar; 2009). The first step in this phase the authors conducted semi-structured interviews with different stakeholders to understand how the information and the material flow through the process and what measures are made throughout the process. Later a process map was drawn in the next step the historical quality data and required qualitative and quantitative data were collected.

In the next step, a quality Survey was conducted. To know the reasons and the most frequently accruing type of defect. Why the product was treated as a defected part and scrapped. Since it was not documented the survey had to be conducted on how the defects were classified at different levels in the organization. Eventually, in this phase fish-bone diagrams were drawn to get an initial idea about the reasons that might have caused a particular type of defect. Also, descriptive statics calculations were carried out along with scattering plots and histograms to calculate the machine process parameter variations.

Training and Interviews

In this phase, the first step was to make familiar with the problem-solving method. The current method of solving the quality-related problems related to this case study with the stakeholders via the interviews. The interview process and the documents collection process are written more in detail in the data collection section. The authors wanted to get familiarize and trained with the manufacturing process used in this case study along with the problem-solving techniques used by the different stakeholders. The historical data related to the quality and production disturbances were collected and analyzed using simple bar charts in excel. Eventually, a correlation coefficient was calculated using the equation 2.9

Process Mapping

The process mapping is carried out mainly for the better understanding of the process in the form of value stream mapping, SPIOC diagram or a flow chart (R.Shankar; 2009). A value stream mapping process was collected from one of the stakeholders to understand the flow of the material and information. A detailed flow chart was drawn by the authors. Where a flow chart is a process which is used to explain every detailed step involved in the process. The detailed injection molding process figure is shown in figure 2.5 and explained in the previous chapter section 2.3.2. Which helped the authors to understand the detailed process of the case study that was conducted.

Quality Survey

A quality survey was conducted by the authors to rank and see the most frequently occurring type of quality defects that were occurring in the manufacturing process with what would be probable cause for the defect according to their opinion. Since there was no documentation for the reasons for scrap parts a survey was conducted at different levels in the organization. The template for the quality survey is as shown in figure 3.2 and the necessity of doing this are explained in detail.

QUALITY SURVEY (For Chalmers Thesis Purpose)

* Would be convenient for us if answered in English but no problem if answered in Swedish as well.

Product A	
Top 3 defects (Topp 3 Defekter)	Causes/Reasons for this Defect (Kassation Orsak) (Based on your opinion)
1.	1.
2.	2.
3.	3.
Comments (if any):	
Your experience Period on this product (How long have you been working on this product)	

Product B	
Top 3 defects (Topp 3 Defekter)	Causes/Reasons for the Defect(Kassation Orsak) (Based on your opinion)
1.	1.
2.	2.
3.	3.
Comments (if any):	
Your experience Period on this product (How long have you been working on this product)	

Figure 3.2: *Quality Survey*

Majority of the data needed for analysis were available but the type of rejections was missing at Plastteknik AB. So, the quality survey had to be carried out at Plastteknik AB with the help of operators and the employees who were involved in manufacturing Product A and Product B. Quality survey template was prepared as shown in the Figure 3.2 for the operators who were working on Product A and Product B, which includes top three defects from their experience working on that particular product and causes for those defects from their point of view and analysis.

The template was inclusive of the operators' experience period in order for us to prioritize their answers accordingly. Template allowed the operators to leave a comment if they wanted to share any information regarding the product that would be helpful for this thesis.

Initially, a quality survey was conducted on the operators working at the shop floor but due to the language and the communication problem, it was difficult for us to make the operators understand the purpose of the quality survey. So, we decided to conduct a Quality Survey on the managers and the team leaders who understood the questions and survey intent, which made it possible to get the required results from the survey. To avoid this kind of time-consuming work and pitfalls the authors recommend to implement Quick view screens explained in next chapter 6 section 6.7.

Fishbone Diagram

The fishbone diagram which is known as the cause and effect diagram and also known as the Ishikawa diagram. Which is a major tool that is used to find a root cause in quality defect-related problems. In this case study, the fishbone diagram was drawn based on the quality survey that was conducted. Individual fishbone diagram was drawn for each type of defect because the root cause for different type of defect should not be generalized. The fishbone diagram is shown and explained in detail in the further chapter 5.1.4 which helped us with further data collection and analysis.

Data Collection

After identifying the primary cause further data collection was made in search of root cause. The machine parameters data were collected to see which manufacturing process parameter affect which type of defect on the product.

Scatter Plots

In this step, all the recorded machine process parameters were plotted on a scattered plot in an excel sheet to see if there is any variation from the ideal values stated at the beginning of the project phase in an FMEA (Failure Mode Effect Analysis) results collected during the data collection phase provided by the stakeholders.

Statistical Analysis

In this step statistical analysis was conducted in the first step since the process is basically a centered based process where there is no UCL (Upper Control Limit) and LCL (Lower Control Limit) defined in FMEA (Failure Mode Effect Analysis) result document provided by the project sponsor. The descriptive statics such as standard deviation, variance, mean, coefficient of variance is calculated using the equations mentioned in the previous chapter section 2.5.2, using excel the results were calculated.

3.2.3 Analyze Phase

Analysis phase was mainly initiated with the help of triangulation method. Mainly, the data from the measure phase were analyzed and further necessary data were collected to find the root cause of the problem. The machine process parameter data were analyzed using scatter plots in excel for the recorded critical parameters and to confirm the results from statistical analysis that was made in the measure phase was considered. Finally, an FTA (Fault Tree Analysis) was carried to find the root cause for each defect with certain literature study and broader discussion and semi-structured interviews with the process specialist. Eventually, to find the interdependence of the logged critical machine process parameters a correlation analysis was carried out in this phase.

FTA (Fault Tree Analysis)

It is a well-established tool used various applications (Vesely, Goldberg, Roberts, and Haasl, 1981) used to find system dependability. It is a top-down approach to find the cause and effect of any event. They are usually conducted at both a quantitative and qualitative level. In this case study, we first conducted it at a qualitative level and later verified the results using different quantitative analysis. The FTA (Fault Tree Analysis) for each type of defect was analyzed with broader discussion from the authors with manufacturing process technician and verified with further statistical analysis and correlation coefficients.

Correlation Analysis

The correlation analysis was done using the equation mentioned in the previous chapter section 2.5.2.2 using excel to see the interdependence of each machine process parameter on both the products.

3.2.4 Improve Phase

In this phase, the actual improvement must be carried out (R.Shankar; 2009) after several literature study and discussion. Specific methods were observed to optimize the critical machine process parameters. The most common ones are the Taguchi method and simple regression analysis. We decided to go with simple regression analysis since, Taguchi method is most commonly used to optimize the process design parameters. Simple regression analysis was proposed by the authors to calculate the optimized machine parameter value. Finally, cost calculation was made to propose some investment potential to reduce the scrap rate.

Also, on the other hand, multiple regression analysis can be carried out in order to predict some output if there are two or more variables affecting an individual output. We were not allowed to carry out physical test. So, no physical tests were conducted as per the delimitation's set by the authors.

Regression Analysis

The process can be optimized using the regression analysis as it's explained in the previous chapter section 2.5.2.3 in detail when a particular input is varied you can predict the change in the output which also takes into consideration various factors into consideration such as the machine wear and the batch of material the environment and, etc. Also, the significance F test and the P test should be conducted to verify the selected sample data from the population. It's necessary to have a suitable sample data to predict the output variable value for a particular input variable to improve the quality of a product (Kavade and Kadam, 2012).

REFERANCE NUMBER	PARAMETERS CONSIDERED											OPTIMIZATION METHOD	RESPONSE STUDIED	NOTATIONS USED
	a	b	c	d	e	f	g	h	i	j	k			
1			*	*	*	*	*	*	*		*	PCA& REGRESSION ANALYSIS	QUALITY	a – FILLING TIME
2	*				*	*	*				*	DOE & KRIGING ALGORITHM	WARPAGE	b – INJECTION TEMPERATURE
3	*				*	*	*				*	ANN & GENETIC ALGORITHM	PARAMETER LEVELS	c – INJECTION SPEED
4			*	*	*	*	*	*		*	*	TAGUCHI METHOD	TENSILE STRENGTH	d – INECTION PRESSURE
5	*				*	*	*	*			*	GENETIC ALGORITHM	RUNNER DESIGN	e – BARREL TEMPERATURE
6	*				*	*	*					TAGUCHI METHOD	WARPAGE	f – HOLDING PRESSURE
7	*	*									*	3D-SIMULATION	FLOW ANALYSIS	g – HOLDING TIME
8	*		*	*								3D-SIMULATION	GATE DESIGN	h– COOLING TIME
9			*			*	*			*		FEM MODELLING	DIMENSIONAL STABILITY	i – SCREW STROKE
*- INDICATES PARAMETERS CONSIDERED AT VARIED LEVELS														j – NOZZLE TEMPERATURE
														k –MOLD TEMPERATURE

Figure 3.3: *The figure shows the different process optimizing tools for various purposes (Kavade and Kadam, 2012).*

3.2.5 Control Phase

This is the last phase of the DMAIC process after considerable implementation of the new improved method and the process is optimized after a very good understanding of the process variability (R.Shankar; 2009). The realization of control over the improved input machine process parameter that affects the output parameter. The process must be standardized and certain action plan has to be carried out to standardize the process and certain work instructions have to be developed to have good control over the process (R.Shankar; 2009). By developing the control charts and operating the critical process parameters under set limitations it's possible to have a stable process. The authors have not carried out this step due to the set delimitations.

3.3 Data Collection

Since the manufacturing process is a bit complex and various parameter need to be considered. In order to have a better understanding of the problem as well as to keep up the quality of work that the authors have carried out in this case study. Data can be generally collected in two ways through qualitative and quantitative research (C. Berlin and C. Adams;2017). Basically, quantitative research focuses mainly on numerical data and the chosen method to solve the problem was a data-driven the authors had to rely more on them (C. Berlin and C. Adams;2017). This involves the measured data from the machines and other numerical data and the interpretation of this data plays a major role in avoiding downsides.

Similarly, qualitative research consists of observations, interviews, discussions, old recorded documents, etc. Since there are various factors that affect the quality of the product from the beginning of the project phase of the product was collected the data collection was done using triangulation methods comparing the recorded data with reality in the shop floor as well as theoretically (C. Berlin and C. Adams;2017). This kind of collection helped the authors for better understanding of the problem and to define the objectives in the earlier stages of the project as well as in the final stage it also helped us to support the finding's during the case study.

3.3.1 Interviews

The Interviews (Focused Groups) is one of the most common methods used by the researchers to get a better understanding of the problem with different perspective about the problem from various stakeholders. In the first phase, general unstructured interviews were conducted with all the stakeholders and experts in various fields to their point of view on the case study which the authors have conducted (Patel and Davidson; 2011) and some questions are stated in Appendix A.1. As it progressed the reasons for the quality defect was not documented we had to conduct a semi-formal survey at different levels within the organization to prioritize which defects to be mainly focused on. Later several semi-structured interviews were conducted to get better feedback about the author's progress and to make sure it's not deviating from our objective. The discussion was an alternative form for the interviews when it was difficult to cover all the stakeholders. To gain the required data as authors we used this method to get the research work done at a faster pace.

3.3.2 Documents

The documents played an important role for the authors to understand the history of the project from the beginning of the project phase, the design feasibility test, the flow simulation result, process mapping, the material, and information flow, the feasibility test of the machine process parameters such as cycle time, melt temperature, injection time and various other documents were studied and compared with the reality what are the actual set parameters were verified using triangulation methods and scattered plots in excel. These documents were compared with external literature resources for better understanding of each parameter.

3.3.3 Observation

The observation plays an important role in data collection as the lean term says Gemba or "Go to See" gave a greater insight to the authors about the problem and factors affecting the manufacturing process. About what kind of documentation is done, the quality checks and many more. The better understanding of the cause and effect relationship without altering the planned study was sustained. It's a good practice as a researcher to "Go to see" for the better understanding of the actual facts rather than only studying the historical recorded documents which might have been wrongly interpreted to actual fact.

3.4 Research Ethics and Quality

When it comes to research ethics four general principles stated by Bryman and Bell were considered which are *"privacy invasion, informed consent, harming participants and deception"* (Bryman and Bell; 2011). The first principle invasion is the acceptance of the freedom from the project sponsor for photographing or filming inside the factory, the products, or humans working photographs. Which the authors did not try to take without the permission only photos taken of the products that were shared by the project sponsor where included. The second one being informed consent provided to the stakeholders about the interviews or the discussion. By sending them emails about the questions that the authors might ask them before the meeting has been scheduled and they had enough time to decide about there participation in the surveys/interviews/ discussion.

The purpose of the surveys/interviews/ discussion were made clear and the anonymity of the participants will be preserved. The third one is harming participants which refer to all kinds such as physical, stress, keeping confidentiality about the participants as well as the sponsoring organization before conducting any task or using the data permission from the project sponsor was attained. The fourth principle the deception which refers to trapping or fishing the stakeholders which were not applicable during the case study (Bryman and Bell; 2011).

According to Yin, there are four tests that can be carried out they are *"construct validity, internal validity, external validity, reliability"* (Yin; 2003). To meet the Construct validity, this case study the authors have used correlation and regression analysis of how the output process parameters vary with an input parameter being varied. To meet the internal validity triangulation approach was used by the authors by verifying the results with different results from literature study, various analysis tools used in the case study, and interviews and discussions. Due to time limitations, no physical test was conducted. The external validity according to the authors are the findings in this case study. Which might be very particular to this case study. Since, the quality of the product depends on the various manufacturing process parameters depending on the quality problem and the product design variation. But the method and tools followed can lead to similar results. However, Yin (Yin; 2003) explains *"when two or more case study can be supported for replication of the case study"*.

Also, he explains *"the analytical generalization of case study findings can be generalized to a broader theory"* (Yin; 2003). As suggested by Yin *"the conceptual methodology designed to solve the quality-related problem can be implemented across various manufacturing process to solve the quality-related problem depending on the standards required and data available in the organization"* (Yin; 2003). To have a good Reliability of the research method well-known and established research methods were used in this case study to have low potential risks because the ultimate aim is to increase the yield of the product.

4
Results

This chapter presents the major findings of the thesis work in phase-wise

4.1 Define Phase

The planning report was outlaid about the master thesis case study that were conducted which consists of an overview of the organization as well as the selection of the project. This document was looked upon and updated as the case study progressed through different phases of the master thesis the initial planning is attached in appendix A.1

4.2 Measure Phase

The results from the different tools used in this phase of the DMAIC process are presented below.

4.2.1 Quality Data Analysis Results and Production Disturbance

One of the major objectives of this thesis work is to find out how production disturbances affected the quality of the product. In order to achieve this, we needed to have a clear picture of the rejected percentage of the two products Product A and Product B in relation to the production disturbance over a certain period which gave us a basic insight to our thesis work.

So, we considered the time period of 7 months from the year 2018 for our analysis. With the help of the Quality Assurance department, we gather the data of both the products in terms of the number of products produced and the number of products rejected. Along with this, we also gathered data on production disturbance in terms of the number of stop time and the stop time in hours.

4.2.1.1 Product A

When it comes to Product A, we analyzed the data from the QA(Quality Assurance) department and calculated the rejected percentage for every month with the help of formulae 4.1,

$$Rejection\ Percentage = (1 - (\frac{A - B}{A}) * 100) \tag{4.1}$$

Where,

A= Number of Products Produced
B= Number of Products Rejected

Looking at the rejection percentage and the total stop time in hours for every month, it was clearly evident that the rejection percentage was clearly proportional to that of the total stop time in hours.

For example, when you consider the month of May, the rejection percentage is 31.28% and the sum of total stop time in hours is 143.08 hours. Similarly, for other months it is reflected in figure 4.1

Month	Number of Scrap Products	Quality Approved	Total Product Produced	Rejection %	Count of Total Stop Time	Sum of Total Stop Time In Hours
Apr	2284	25368	27652	8.26	483	134.82
May	11851	26040	37891	31.28	686	143.08
Jun	2903	21120	24023	12.08	398	145.14
Jul	4966	22120	27086	18.33	392	143.79
Aug	3279	21696	24975	13.13	394	113.61
Sep	8454	26196	34650	24.40	631	121.37
Oct	5502	33876	39378	13.97	733	124.80
Total Product Produced	39239	176416	215655	18.20	3717	926.61

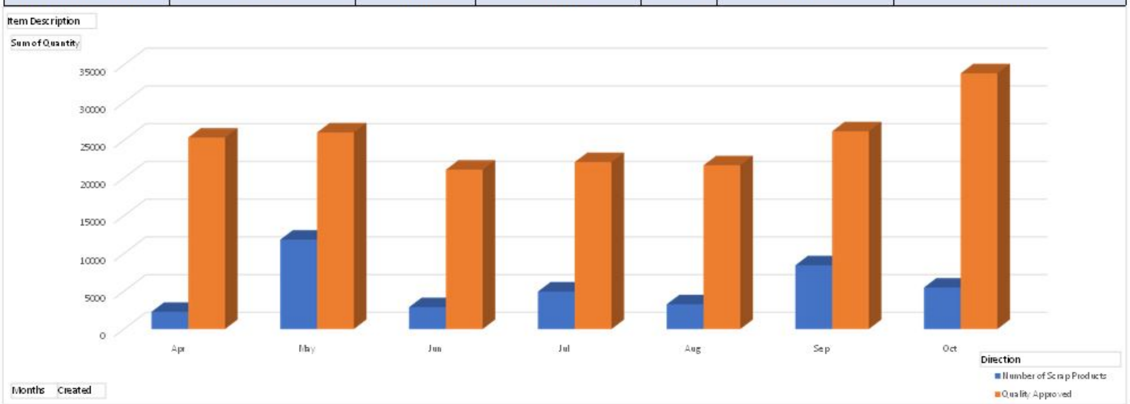

Figure 4.1: *Quality Data: Product A*

A correlation coefficient was calculated using excel and the equation 2.9. The rejection percentage had a positive correlation coefficient of 0.52 and 0.16 with respect to count on total stop time and sum of total stop time in Hours. This was calculated to see how production disturbance correlate with the quality of Product A which also answers our first research question.

4.2.1.2 Product B

Similar analysis was carried out for Product B, where the rejection percentage of Product B for every month (from April To October 2018) was calculated with the help of formulae 4.2,

$$Rejection\ Percentage = (1 - (\frac{A - B}{A}) * 100) \tag{4.2}$$

Where,

A= Number of Products Produced
B= Number of Products Rejected

The rejection percentage of Product B in the month of May its 6.19% and the sum of total stop time in hours is 350.11 hours. A similar analysis was done for the rest of the months which is shown in figure 4.2

When you consider the overall time period of 7 months the rejection percentage is 4.06 the corresponding count of total stop time and the sum of total stop time in hours are 2769 and 1668.22 hours respectively.

A correlation coefficient was calculated using excel and the equation 2.9. The rejection percentage had a positive correlation coefficient of 0.38 and 0.42 with respect to count on total stop time and sum of total stop time in hours. This was calculated to see how production disturbance correlate with the quality of the Product B which also answers our first research question.

Month	Number of Scrap Products	Quality Approved	Total Product Produced	Rejection %	Count of Total Stop Time	Sum of Total Stop Time In Hours
Apr	3258	103746	107004	3.04	292	195.26
May	7233	109549	116782	6.19	460	350.11
Jun	6347	104360	110707	5.73	315	155.63
Jul	1721	91330	93051	1.85	253	199.28
Aug	1907	74491	76398	2.50	191	176.83
Sep	4457	110489	114946	3.88	430	226.41
Oct	5489	124740	130229	4.21	828	364.70
Total Product Produced	30412	718705	749117	4.06	2769	1668.22

Figure 4.2: *Quality Data: Product B*

4.2.2 Quality Survey

The type of rejection on both these products Product A and Product B was missing, so we had to carry out a quality survey. Where we created a template for the employees of Plastteknik AB, which includes top three defects from their experience on working on that particular product and causes for those defects from their point of view and analysis.

We also included their experience period in order to prioritize their answers accordingly. We did allow them to leave a comment if they wanted to share any information regarding that product that would be helpful for this thesis.

4.2.2.1 Product A

Quality Survey template for Product A is as shown in figure 3.2. Quality Survey was conducted on five employees of Plasttennik AB. Quality Survey revealed that the top three major problem or the top three defects in Product A were;

1. Imbalance.
2. Start-up Parts and
3. Axial Run-out.

Causes of defects that were mentioned by the employees were taken into consideration for further analysis and it gave us an insight as to what to expect in our further investigation.

4.2.2.2 Product B

Quality Survey template for Product B is as shown in figure 3.2. Quality Survey was conducted on five employees of Plasttennik AB. Quality Survey revealed that the top three major problem or the top three defects in Product B were;

1. Cracks.
2. Burn Marks and
3. Angel's Hair.

Causes of defects that were mentioned by the employees were taken into consideration for further analysis and it gave us an insight for further investigation.

4.2.3 Fish Bone Diagram

The probable cause for each defect was listed by the authors using the results obtained from the focused interviewees, literature study and documents collected. The results obtained were verified using a triangulated approach and transferred them in the form of a fish-bone diagram. This results helped us for further data collection and the areas that the authors had to focus on further findings.

From the results, it was evident that for burn marks, cracks, angels hair, axial run-out and imbalance type of defects needed focus on the process parameters to control the quality of the product and startup parts were due to poor management issues. Fish-bone diagram for each defect is shown in the Appendix A.4.

4.2.4 Machine Log Data Analysis Results (Scatter plot or Dot plot)

Machine number 134 was responsible for producing Fan V54X and machine number 137, 139 and 147 were responsible for producing Carrier plates. During the injection molding process, there are several parameters that are responsible for the quality of the product produced, where some are considered critical parameters. These machine data were logged in an external USB device at Plastteknik AB, which was then analyzed and the results are reflected in the subsections below.

4.2.4.1 Product A

The parameters that were logged in machine number 134 that is responsible for producing Product A are as follows;

1. Cycle Time in Seconds.
2. Dosing or Metering Time in Seconds.
3. Specific Pressure When Switching in Bars.
4. Mass Pillow Minimum Value in Cubic Centimeters.
5. Injection Time in Seconds.

In order to have a clear picture of the analysis, plotting of each parameter from the machine data was done on the same plot in such a way that it includes the best day (the day when they had zero rejection) data along with that of the worst day (the day when they had maximum rejection) data and the ideal value as per simulation results during the project phase. As per the Quality Assurance department data Product A had a maximum rejection of 84.65% on 9th May 2018 and zero rejection on 2nd September 2018.

Once we plotted all the different parameters machine data as mentioned earlier, it was evident that there was some deviation from the ideal value. Acceptable deviation from the ideal value is one percent but there were few major deviations from the ideal value, especially when you look at specific pressure when switching in the figure 4.3. The white line indicates the ideal value, the red line indicates the machine data on 9th May 2018 and green line indicates machine data on 2nd September 2018.

In order to be able to isolate the variations in the filling phase, short shots were produced without holding pressure. Screw movement was stopped at a defined switch-over position representing a fill level of about 95%. With increasing viscosity, the set switch-over pressure will be reached too early than required. Since the melt front will not have reached the desired filling level, there will be variations in the molded part. In our case, the high precision of the screw-positioning system is absolutely necessary in order to execute exactly the desired compensation through a deliberate change in the switchover point (Pilwein, 2014), which would, in turn, result in high-quality products.

Figure 4.3: *Machine Log Data-Specific Pressure When Switching: Product A*

4.2.4.2 Product B

The parameters that were logged in machine number 137,139 and 147 that were responsible for producing Product B are as follows;

1. SFs in Seconds.
2. Lock Force in KN.
3. ZDry in Seconds.
4. Time to Lockup in Seconds.
5. Time to Buildup Locking Force in Seconds.
6. Cycle Time for Mould Closure in Seconds.
7. Cycle Time for Mould Opening in Seconds.

Similar to that of Product A, plotting of each parameter from the machine data for Product B was done on the same plot in such a way that it includes the best day (the day when they had zero rejection) data along with that of the worst day (the day when they had maximum rejection) data and the ideal value as per simulation results during the project phase. As per the Quality Assurance department data Product B had a maximum rejection of 40.84% on 15th May 2018 and zero rejection on 11th September 2018.

Even though there were few deviations from the ideal value in case of SFs, ZDry, time to lockup, time to buildup locking force, cycle time for mold closure and cycle time for mold opening, there was no clear pattern that could lead us in finding the root cause of the problem. But when we analyzed SKs lock force in KN as shown in the figure 4.4, where white line indicates the ideal value, red line indicate machine data on 15th May 2018 and green line indicate machine data on 11th September

2018 we could see a clear pattern.

Lock Force is the force required to keep the mold closed during injection and it must exceed the force given by the product of the live cavity pressure and total projected area of all impressions and runners (Dominick).

As we can see in the figure4.4 the ideal lock force is around 15123 KN but on both the days, that is on 15th May and 11th September there is clearly a major deviation from the ideal value. Especially when you look at the data on 15th May the locking force has exceeded the ideal value by 1100 KN.

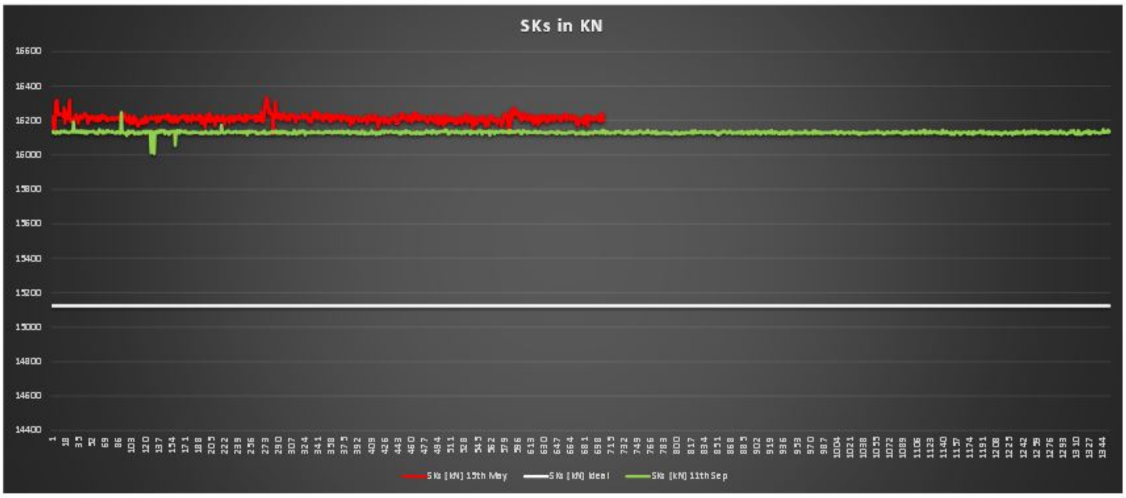

Figure 4.4: *Machine Log Data-Lock Force: Product B*

4.2.5 Statistical Analysis Results

As explained in the earlier chapter this process is a centered based process (mean based process). Descriptive statistical analysis was carried out for the entire population to know the variance, standard deviation, coefficient of variance for different machine process parameters for both Product A and Product B. The population (data set) chosen is similar to the one chosen for machine log data analysis (scatter plot analysis).

4.2.5.1 Product A descriptive statistical analysis results

From the table 4.5 it was evident that Specific Pressure When Switching (switch-over pressure), Cycle time, the Mass Pillow Minimum Value and Injection Time had differences in their statistical values. Calculated using the equation shown in chapter 2 when compared with highest rejection day and lowest rejection day. This result gave a hint, on the quality related problems might be because of the variation in process parameter. Out of the several parameters that had variation in the compared result within the chosen population from the authors. Switch over-pressure had more variation which will lead to variation in the shape of the final product.

	ZUs [s] Cycle time	ZDx	APHu [bar] switch over pressure	APCx	ZSx [s] injection time	SFx [mm]
VARIENCE	10.48	0.43	1910.46	7.76	0.0087	
STANDARD DEVIATION	3.23	0.65	43.72	2.78	0.093	
COEFFICIENT OF VARRIENCE	5.69	4.88	4.21	2.50	3.02	
MEAN	56.85	13.42	1037.06	111.30	3.08	
MINIMUM	56.19	13.64	1044.5	110.6	3.07	
MAXIMUM	97.76	14.33	1124.2	124.93	3.72	
VARIENCE	2.61	0.36	1150.18	1.70	9.06E-05	0.0057
STANDARD DEVIATION	1.61	0.60	33.91	1.30	0.0095	0.076
COEFFICIENT OF VARRIENCE	2.92	4.28	4.07	1.14	0.27	0.0075
MEAN	55.26	14.02	833.06	114.47	3.40	1001.35
MAXIMUM	104.86	17.98	957.9	116.61	3.43	1001.7
MINIMUM	49.58	7.67	521	4.42	3.03	1001.1

Figure 4.5: *The table shows different statistical values for Product A compared between highest rejection and lowest rejection*

4.2.5.2 Carrier plate descriptive statistical analysis results

	SFs [mm]	SKs [kN]	ZDry [s]	ZEve [s]	ZSKa [s]	ZSchl [s]	ZOeff [s]
MEAN	1324.19	16211.89	7.51	1.36	0.84	4.12	6.69
MINIMUM	1324	16119.9	7.48	1.31	0.83	4.09	6.56
MAXIMUM	1324.3	16330.8	10.01	1.42	3.35	6.62	6.76
VARIENCE	0.0034	470.34	0.012	0.0006	0.0093	0.011	0.0003
STANDARD DEVIATION	0.058	21.68	0.10	0.024	0.096	0.10	0.019
COEFFICIENT OF VARIENCE	0.0044	0.13	1.45	1.8	11.45	2.65	0.28
MEAN	1325.58	16130.04	7.16	1.45	0.90	4.27	6.28
MINIMUM	1325.4	16007.2	4.26	0	0.88	4.23	0
MAXIMUM	1325.8	16246.5	9.34	1.59	2	6.45	6.41
VARIENCE	0.0047	70.74	0.021	0.0043	0.0020	0.012	0.059
STANDARD DEVIATION	0.069	8.41	0.14	0.065	0.044	0.11	0.24
COEFFICIENT OF VARIENCE	0.0052	0.052	2.045	4.52	4.94	2.62	3.88

Figure 4.6: *The table shows different statistical values for Product B compared between highest rejection and lowest rejection*

From the table 4.6 it is evident the Lock Force had differences in their statistical values calculated using the equation shown in chapter 2 section 2.5.2 in excel when compared with the highest rejection day and lowest rejection day. The lodged machine process parameter, that was evident which did not very much on both days were SFs, ZDry, Time to Lockup, Time to Buildup Locking Force in Seconds, Cycle Time for Mould Closure and Cycle Time for Mould Opening.

This result gave evidence that there might be a possibility that the process parameter variation might be the cause for quality-related problems. It was evident that from the discussion with the focused groups and various literature studies. When the chosen population had a large variation in lock force which leads to a defect called Flash (an extra material that comes at the edges or near the threads of the profile of the product) and burn-marks on the product.

4.2.6 Correlation Analysis

The correlation analysis is carried out to see the interdependence of two continuous variables. More about Correlation analysis can be viewed in chapter2under section2.5.2.2 formulas.

4.2.6.1 Product A

	APHu [bar]	ZUs [s]	ACPx [cm3]	ZSx [s]	ZDx [s]
APHu [bar]	1				
ZUs Actual [s]	0.21	1			
ACPx Actual [cm3]	-0.78	-0.25	1		
ZSx Actual [s]	-0.80	-0.24	0.92	1	
ZDx Actual [s]	-0.19	-0.28	0.14	0.15	1

	APHu [bar]	ZUs [s]	ACPx [cm3]	ZSx [s]	SFx [mm]	ZDx [s]
APHu [bar]	1					
ZUs [s]	-0.010	1				
ACPx [cm3]	0.087	0.93	1			
ZSx [s]	-0.015	0.96	0.97	1		
SFx [mm]	0.017	-0.96	-0.97	-0.99	1	
ZDx [s]	-0.19	0.0069	0.016	0.017	-0.021	1

Figure 4.7: *The table shows correlation results for Product A compared between highest rejection and lowest rejection*

In the table 4.7 Product A correlation coefficient results can be seen with the different machine process parameters. The Mass Pillow Minimum Value in Cubic Centimeters and Injection Time in Seconds have a negative correlation coefficient of -0.78 and -80 with respect to Specific Pressure When Switching in Bars. On the other hand, Injection Time in Seconds has a positive correlation coefficient of correlation of 0.92 with respect to Mass Pillow Minimum Value in Cubic Centimeters. The remaining machine process parameters do not seem to have much interdependence in the selected population. The above-mentioned results were are on highest rejection day.

Similarly, when we see the results for a low rejection day the cycle time in seconds has a positive correlation coefficient of 0.93 and 0.96 with respect to Specific Pressure When Switching in Bars and the Injection Time in Seconds. Likewise, SFx has a negative correlation coefficient of -0.96,-0.97,-0.99 with respect to cycle time in seconds, Mass Pillow Minimum Value in Cubic Centimeters and Injection Time in Seconds. Also, Injection time in second has a positive correlation coefficient of 0.97 with respect to Mass Pillow Minimum Value in Cubic Centimeters.

When we compare both the tables the authors found that some machine parameters which had both positive and negative correlation on the lowest rejection day did not have that percentage of correlation on the highest rejection day. Were as the correlation coefficient of Injection time in seconds with respect to Mass Pillow Minimum Value in Cubic Centimeters interdependence did not vary on both days.

4.2.6.2 Product B

	SFs [mm]	SKs [kN]	ZDry [s]	ZEve [s]	ZSKa [s]	ZSchl [s]	ZOeff [s]
SFs [mm]	1						
SKs [kN]	0.011	1					
ZDry [s]	0.065	-0.11	1				
ZEve [s]	0.0057	-0.15	-0.016	1			
ZSKa [s]	0.091	-0.022	0.88	-0.039	1		
ZSchl [s]	0.068	-0.10	0.99	-0.016	0.88	1	
ZOeff [s]	0.010	-0.09	0.012	0.90	-0.036	0.0072	1

	SFs [mm]	SKs [kN]	ZDry [s]	ZEve [s]	ZSKa [s]	ZSchl [s]	ZOeff [s]
SFs [mm]	1						
SKs [kN]	-0.063	1					
ZDry [s]	0.041	-0.11	1				
ZEve [s]	0.0014	-0.0067	0.56	1			
ZSKa [s]	0.0095	-0.38	0.34	0.039	1		
ZSchl [s]	0.041	-0.15	0.65	-0.1	0.44	1	
ZOeff [s]	0.013	0.0053	0.64	0.9	0.01	-0.13	1

Figure 4.8: *The table shows correlation results for Product B compared between highest rejection and lowest rejection*

In the table 4.8 we can see ZDry in seconds has a positive correlation coefficient of 0.88, 0.99 with respect to Time to Buildup Locking Force in Seconds and Cycle Time for Mould Closure in Seconds respectively. Likewise, Time to Buildup Locking Force in Seconds has a positive correlation of 0.88 with respect to the Cycle Time for Mould Closure in Seconds. While the Time to Lockup in Seconds has a positive correlation of 0.9 with respect to the Cycle Time for Mould Opening in Seconds on both the compared days.

When both the highest rejection and the lowest rejection data are compared with each other we can see the difference in the interdependence of the machine process parameters.

4.3 Analyze Phase

In this section, the results for different defects and their root cause for the defect are presented and the results from how to predict various quality-related failures are presented.

4.3.1 Literature Review

Common defects in injection molding and ways of avoiding

In this literature by Vyacheslav et al, 2018 common defects that occur in injection molding and necessary steps to avoid these defects are highlighted using different methods (Vyacheslav et al, 2018). The authors in this study have listed the type of defect that occurs in the molding of plastics and causes for this defect and how to avoid these defects. Also, along with it they have mentioned at which part of the cycle this defect will occur.

On the other hand, in a case study from (Kavade and Kadam, 2012) has listed the parameters that can be optimized using various tools or methods that can be used in various circumstances which is shown in the figure 3.3 as helped us in the master thesis to get the basic ideas to find the root cause of the defects in this case study.

Use of temperature and pressure sensors

By using temperature and pressure sensors melt temperature, mold temperature, Pressure inside the mold can be measured. Since they are the most important parameters to avoid defects its necessary to measure this parameter to control the real-time quality of the products (Kumar et al. 2019). Also, a study from Alireza Akbarzadeh and Mohammad Sadeghi in (2011) says to avoid defects using melt temperature, packing pressure and packing time are most influential parameters (Alireza Akbarzadeh and Mohammad Sadeghi, 2011).

Use of regression analysis to optimize process parameters

The authors in this case study found that quality in injection molding process can be controlled using statistical methods from the case study Kavade and Kadam, (2012) and Alireza Akbarzadeh and Mohammad Sadeghi, (2011). Also, Kavade and Kadam, (2012) have said in their conclusion "the experimental method can be analogically applied to most of the polymers with some minor deviations" (Kavade and Kadam, 2012).

4.3.2 FTA (Fault Tree Analysis) Results

Fault Tree Analysis (FTA) also known as a top-down approach, proves to be one of the best methods which help us to identify potential causes of system failures or root cause of a problem.

4.3.2.1 FTA Product A Imbalance

The first major problem in case of Product A was Imbalance, because of which most of the products were rejected. In order to find the root cause of the problem we carried out FTA as shown in figure 4.9.

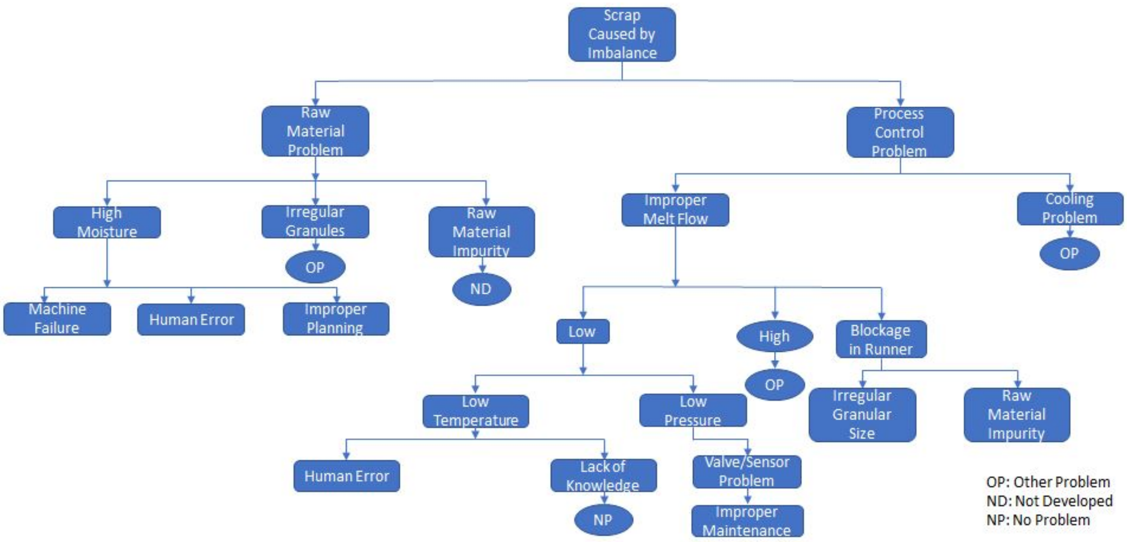

Figure 4.9: *FTA (Fault Tree Analysis) Results: Product A Imbalance*

Scrap due to imbalance in Product A can occur either because of the problem in the raw material or because of the process control problem.

A problem in raw material can either be because of high moisture or irregular granules or raw material impurity. High humidity in raw material can occur because of machine failure or human error or improper planning. But looking at the Product A, raw material humidity test report for the period 2018 it was evident that there was no problem with the humidity of the raw material, moisture content of raw material was within the acceptable range. Whereas raw material impurities and irregular granules were never diagnosed or checked during the production phase.

Process control problem may arise because of improper melt flow or cooling problem. The cooling problem might lead to other problems such as burn marks, so concentrating more on improper melt flow. When it comes to the melt flow, it can be low, high or even partial blockage in the runner. So, low melt flow can occur either because of low melt temperature or low pressure. Where low melt temperature can either be because of human error or lack of knowledge to the operators. We couldn't get access to the melt temperature inside the mold since there were no temperature sensor inside the mold.

One more thing that could have contributed to low melt flow is a low pressure, which might be a result of a valve or sensor problem. During the discussion we had with the technician and maintenance department, they revealed that there were problems with the wear and tear of the screw sensors and the valve tip because of improper maintenance and glass fibers being used as one of the raw material. During our discussion, the technician even mentioned that partial blockage of the runners being observed in his previous encounter in solving imbalance problems.

4.3.2.2 FTA Product A Start-up Parts

The second major problem in the case of Product A was Start-up Parts, because of which most of the products were rejected. In order to find the root cause of the problem we carried out FTA as shown in figure 4.10.

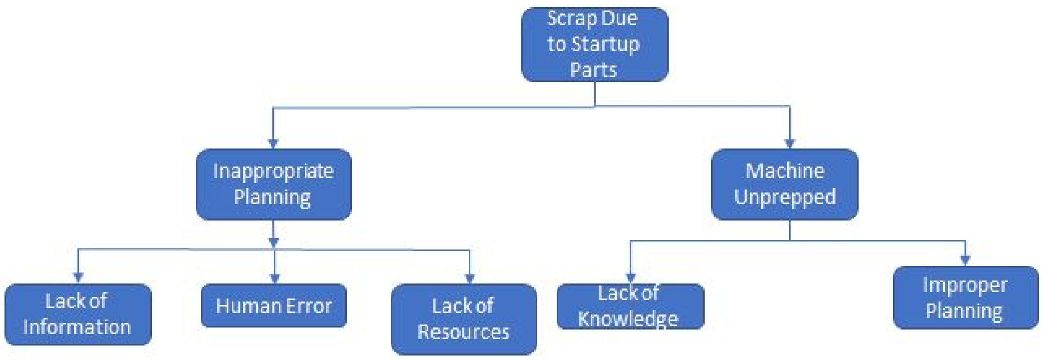

Figure 4.10: *FTA (Fault Tree Analysis) Results: Product A Start-up Parts*

Scrap due to start-up parts in Product A can occur either because of the inappropriate planning or the machine being unprepared.

Where inappropriate planning might be caused due to lack of information or human error or lack of resources. Lack of information includes a lack of raw material information, lack of manpower availability, machine availability information, and logistics information. Human error might be a result of lack of training, lack of knowledge and lack of attitude.

When it comes to the machine being unprepared, might be as a result of lack of knowledge or improper production planning.

4.3.2.3 FTA Product B Burn Marks

When it comes to the Product B, the major problem they were facing was Burn Marks, because of which most of the products were rejected. In order to find the root cause of the problem we carried out FTA as shown in figure 4.11

Burn Marks in Product B can be caused by three major reasons, it can be either because of problem with the raw material or process control problem or problem with the mold vents.

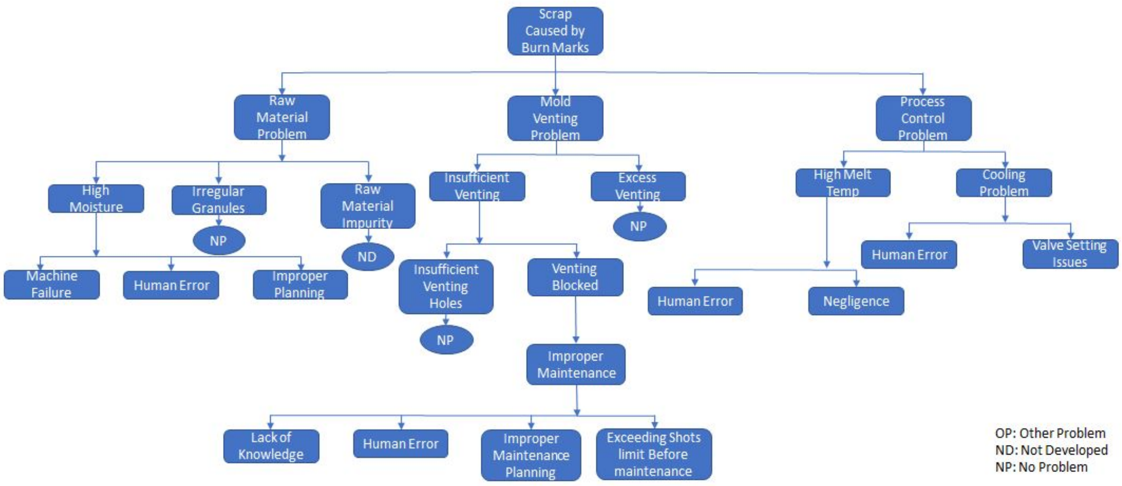

Figure 4.11: *FTA (Fault Tree Analysis) Results: Product B Burn Marks*

Similar to what was mentioned in FTA of Product A regarding raw material, a problem in raw material can either be because of high moisture or irregular granules or raw material impurity. High humidity in raw material can occur because of machine failure or human error or improper planning. But looking at the Carrier Plate raw material humidity test report for the period 2018 it was evident that there was no problem with the humidity of the raw material, moisture content of raw material was within the acceptable range. Whereas raw material impurities and irregular granules were never diagnosed or checked during the production phase.

Process control problem may arise because of high melt temperature or cooling problem. Where high melt temperature might be a result of human error or cooling problem. Whereas cooling problem might arise because of valve setting issues or human error.

One major thing that could have contributed to Carrier Plate burn marks is the problem with the mold venting. Mold venting problem can arise because of two reasons, either insufficient venting or excessive venting. Excessive venting leads to other problems so, focusing more on insufficient venting problem. Insufficient venting problem arises either because insufficient venting holes or venting holes being blocked.

Blockage of vents is a result of improper maintenance of the die. Looking at the major contributors of improper maintenance, it can be either human error or lack of knowledge or improper maintenance planning or exceeding shots limit before the die is taken for maintenance.

4.3.2.4 FTA Product B Cracks

The second major problem with the quality Product B was cracks, because of which majority of the Product B were rejected. In order to find the root cause of the problem we carried out FTA as shown in the figure 4.12

Cracks in Product B can be caused by three major reasons, it can be either because of the problem with the raw material or die design issues or process control problem.

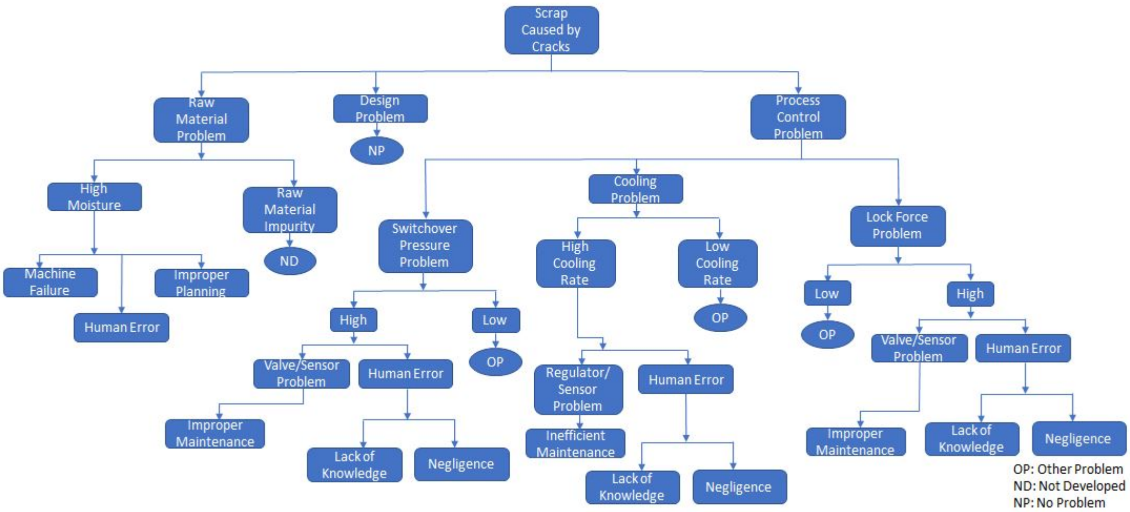

Figure 4.12: *FTA (Fault Tree Analysis) Results: Product B Cracks*

Similar to what was mentioned in the previous section regarding raw material, a problem in raw material can either be because of high moisture or raw material impurity. High humidity in raw material can occur because of machine failure or human error or improper planning. But looking at the Product B raw material humidity test report for the period 2018 it was evident that there was no problem with the humidity of the raw material, moisture content of raw material was within the acceptable range. Whereas raw material impurities were never diagnosed or checked during the production phase. Die design were not analyzed since it was considered as one of the delimitations of this thesis work.

Process control problem may arise either because of the problem with the switch overpressure or cooling problem or lock force problem. Where switch over a problem is a result of high or low switch overpressure. Low switch over pressure leads to other problems so, concentrating on the high switch overpressure. High switch over pressure arises because of valve or sensor problem or either human error. Human errors are a result of lack of knowledge or negligence in their work. Valve or sensor problem is mainly because of irregular and improper maintenance.

The cooling problem arises when the cooling rate is either high or low. Low cooling rate leads to other problems such as burn marks so, concentrating on high cooling rate. A major contributor to the high cooling rate is either a sensor or regulator problem or because of the human error. The human error is the result of negligence or lack of knowledge. Whereas the sensor or regulator problem is a result of improper maintenance.

Major contributors to the locking force problem are either low or high lock force. Where low lock force leads to other problems so, concentrating on high lock force. High lock force is a result of a valve or sensor problem or because of human error. Improper maintenance leading to a sensor or valve problem.

4.3.3 Regression analysis

It's a method to predict the output variable for a single input variable or a multiple-input variable more about regression is explained in the section. 2.5.2.3

4.3.3.1 Product A

The table 4.13 shows the excel regression result to predict the output variable Y which is Specific Pressure when Switching in Bars in the table 4.13 shown. On the other hand, the injection time in seconds being considered as an input variable. The resulting equation is as stated in equation 4.3

$$Y = 2200.91 + (-376.92)X \tag{4.3}$$

Further, the equation 4.3 was verified seeing to the significance F result and the P-value from the table 4.13 verifies the equation 4.3 that can be used to predict the Specific Pressure when Switching in Bars from the chosen population.

Similarly, when the regression analysis was carried out for the lowest rejection day in excel which is as shown in the table 4.14 the calculated equation was not suitable to predict the output variable for a varying input continuous variable from the obtained F test results.

Regression Statistics								
Multiple R	0.80	Correlation Coefficient						
R Square	0.64	Coefficient of determination						
Adjusted R Square	0.64							
Standard Error	25.92							
Observations	1395							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	1728520	1728520	2570.87	0			
Residual	1393	936577.6	672.34					
Total	1394	2665097						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2200.91	22.96	95.84	0	2155.86	2245.96	2155.86	2245.96
ZSx Actual [s]	-376.92	7.43	-50.7	0	-391.51	-362.34	-391.51	-362.34

Figure 4.13: *The table shows regression results for Product A on a highest rejection day*

Regression Statistics								
Multiple R	0.015	Correlation Coefficient						
R Square	0.00024	Coefficient of determination						
Adjusted R Square	0.00018							
Standard Error	33.89							
Observations	14737							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	4205.71	4205.71	3.66	0.05			
Residual	14735	16924659	1148.6					
Total	14736	16928864						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	833.37	0.31	2616.09	0	832.75	833.99	832.75	833.99
ZSx [s]	-0.084	0.044	-1.91	0.055	-0.1718	0.002	-0.17	0.002

Figure 4.14: *The table shows regression results for Product A on the lowest rejection day*

4.3.3.2 Product B

The regression result for the Product B is shown in the table 4.15 and 4.16 the parameters chosen in this analysis are Cycle Time for Mould Opening in Seconds as the output and the Time to Lockup in Seconds as the input continuous variables. On both the days, the F and the P test conducted for the derived equation were in an acceptable range. Hence both the equations for the population can be used to predict the output variable from the chosen population.

Regression Statistics									
Multiple R	0.9								
R Square	0.81								
Adjusted R Square	0.81								
Standard Error	0.010								
Observations	706								
ANOVA	Zoeff VS	ZEve [s]							
	df	SS	MS	F	Significance F				
Regression	1	0.35	0.35	3156.83	2.3E-262				
Residual	704	0.078	0.00011						
Total	705	0.42							
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-6.37	0.13	-46.27	1.1E-215	-6.64	-6.1	-6.64	-6.1
ZOeff [s]	1.15	0.02	56.18	2.3E-262	1.11	1.19	1.11	1.19

Figure 4.15: *The table shows regression results for Product B on a highest rejection day*

Regression Statistics									
Multiple R	0.90								
R Square	0.82								
Adjusted R Square	0.82								
Standard Error	0.027								
Observations	1353								
ANOVA	ZEve [s] VS	ZOeff [s]							
	df	SS	MS	F	Significance F				
Regression	1	4.81	4.81	6407.39	0				
Residual	1351	1.01	0.00075						
Total	1352	5.83							
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.087	0.019	-4.53	6.35E-06	-0.12	-0.049	-0.12	-0.049
ZOeff [s]	0.24	0.003	80.04	0	0.23	0.25	0.23	0.25

Figure 4.16: *The table shows regression results for Product B on a lowest rejection day*

4.4 Cost Analysis Results

This section gives an insight into the consequences of the production disturbances and its effects in terms of cost and sustainability.

4.4.1 Product A

During the period of 7 months (from April 2018 to October 2018) the number of Product A produced were 2,15,655 numbers, out of which 39,239 numbers were rejected during operation, 35 numbers were rejected from the customer side which means that 1,76,381 numbers were quality approved products. Production cost per product is 4.40 Euros, which means that the total cost of rejection for Product A over a period of 7 months (from April 2018 to October 2018) is 1,72,805 Euros.

With cycle being 53 seconds and total numbers of rejected parts being 39,274 numbers, total machine time lost is around 578 hours. Weight of one product is 692 grams, so the total weight of the scrap during production is around 27,177 Kilograms.

4.4.2 Product B

Similarly, when it comes to Product B over a period of 7 months (from April 2018 to October 2018) the number of Product B produced were 7,49,117 numbers, out of which 30,412 numbers were rejected during operation, 484 numbers were rejected from the customer side which means that 7,18,221 numbers were quality approved products. Production cost per product is 6.80 Euros, which means that the total cost of rejection for Product B over a period of 7 months (from April 2018 to October 2018) is 2,10,093 Euros.

With cycle being 26 seconds and total numbers of rejected parts bring 30,896. The total machine time lost is around 223 hours. Weight of one product is 1216 grams. so, the total weight of the scrap during production is around 37,569 Kilograms.

Overall, when you consider both the products Product A and Product B, total number of products produced were 9,64,772 numbers out of which 70,170 numbers were rejected. Rejection of 70,170 numbers led to massive scrap weight of 64,746 kilograms.

5
Discussion

Generally, there are several approaches to tackle problems related to quality and sustainability based on the production flow and data available. Also, along with this the results obtained and the research questions will be disused in and addressed in stages below;

5.1 General Theory and case study discussions

In this section, the authors have discussed the general theory related to the master thesis and problems encountered during the case study.

5.1.1 Production system

A production system is a conversion of an input to the desired output this can be related to the context of a manufacturing process in this master thesis described by Harrington (Bellgran and Säfsten, 2010). In the process of converting raw material into a finished plastic product. There are several elements in a structured production system in the form of disturbances that affect the system not to behave in a stable manner, whereas in this master thesis it was completely true and comparative (Bellgran and Säfsten, 2010).

The production disturbances in this are more related to the disturbances in the form of planning, maintenance, and process optimization of the injection molding manufacturing process that gets affected by these disturbances in the transformation of raw material into a finished defect-free product. The interconnection of each process steps and output from one process is an input to the next step in the process. i.e. The output from the drying of raw material will be an input to the injection molding process.

5.1.2 Choice of product and analysis time period

Basically, the way of tackling production disturbance and quality problems are complicated and implementation of the changes to the betterment of the organization is a humongous task. Product A and Product B were chosen for analysis because Plastteknik AB requested us to concentrate on those two products. Since they were very expensive products and very complicated to manufacture and tackle problems related to these Product A and Product B. The material used is Polypropylene (PP) and Polyamide (PA66) respectively.

The reason for choosing a time period of 7 months from April 2018 to October 2018 was based on the availability of data at Plastteknik AB. There was in need of basic data's such as the number of products produced, the number of products rejected, types of rejection, production disturbances data, machine data, and raw material quality data. Since the data captured in the year, 2018 was trustworthy and systematically captured it was chosen for analysis. One more reason for choosing the year 2018 for analysis was, Plastteknik had major issues with their product quality in the year 2018.

5.1.3 Quality theory

This forms the trigger to follow the DMAIC continuous improvement process approach taken in this master thesis which has formed the core of this case study. Quality is an important aspect of every industry to have better control over the process and foreseeing the outcomes of the process (Siva, 2017). Referring to the quality management topic the principles, the tools, and the methodologies have made the authors realization of the new solution which helps the organization in achieving high-quality and stable process in producing plastic parts (Siva; 2017). Six Sigma, DMAIC process is proved as one of the best methodologies to find quality related solutions for open problems in manufacturing industries (Alkahtani et al, 2016) (Lande et.al, 2016).

On the other hand, it can be contended that there are other methods that could have been used in this master thesis. The quality of the products was the top priority from the start of this master thesis and how different production disturbances affect the quality of the product at various circumstance have been discussed. Quality remained as an important aspect throughout the master thesis and in the future as well.

5.1.4 Approach to Quality Problem

Reverse approach (tracking the products from the finished stage to the raw material stage) was adopted in order to tackle the quality problem since the majority of the data were systematically available and Plastteknik AB was aware that they were facing problems with the quality of the product. So, during initial stages, data and information were gathered from the quality department to know the percentage of rejection on both the products over a period of 7 months from April 2018 to October 2018.

Once the percentage of rejection over a period of time was known, we moved to machine data analysis. But most of the critical parameters were missing when it comes to the machine data that were captured by the technicians and the quality department. Several parameters are responsible for the quality of the product but only a few critical parameters will have a major impact on the quality, which was decided with the help of fishbone diagram as shown in the figure 5.1.

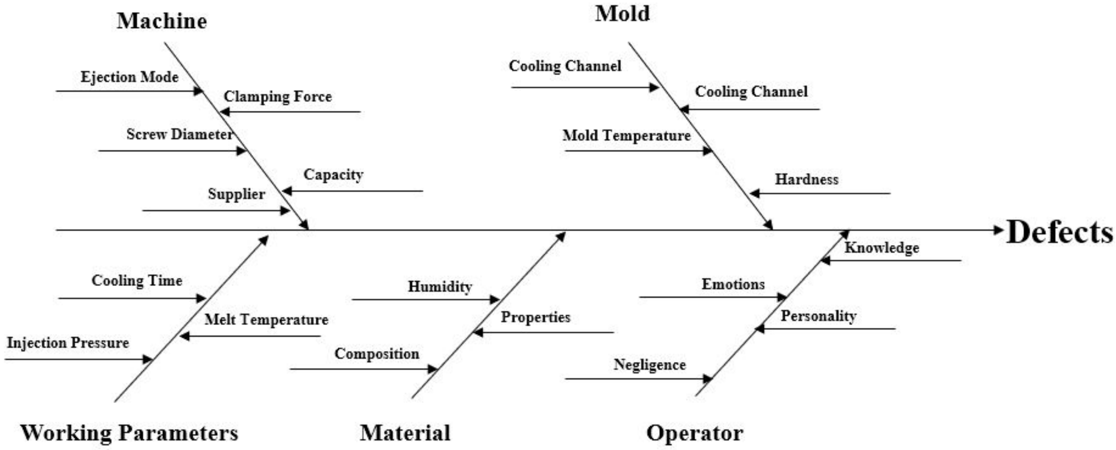

Figure 5.1: *Fish Bone Diagram (Tidke et al, 2014)*

When it comes to the quality of the raw material, the humidity check of raw material was regularly conducted. But raw material quality in terms of raw material purity and granular size were not monitored. Which is explained clearly in the future recommendation section

5.2 Optimized method

The advent of the optimized method as a solution to control the quality of the product and control the process parameter that affects the quality. To help the organization to solve the quality-related problems through the DMAIC methodology by suggesting various tools in various stages of the process. The stakeholders were suggested to use data-based and statistical-based problem-solving methods to control the critical parameters in the injection molding process. The importance of data management and tracking of products plays a vital role since several parameters are responsible for the quality of the product.

Finally, the importance of production disturbance in the form of maintenance, planning and various other functions that disturbs the quality of the product was highlighted in this master thesis. This will eventually, benefit the organization to conduct smooth, hazel free and smart solutions to quality problem.

5.3 Application of DMAIC method in this case study

DMAIC is a continuous improvement process used in most of the industries to stay competitive in the market (Aartsengel and Kurtoglu, 2013). Aartsengel and Kurtoglu have also made a statement *"to see DMAIC methodology has a longterm business investment for the industries"* (Aartsengel and Kurtoglu, 2013). The built methodology in this master thesis has realized an optimized method to solve the quality-related problem as well as optimize the critical process parameter which is a laid foundation for various continuous improvement in various aspects of process improvement.

In this case study, the Six Sigma methodology was adopted to accomplish the objectives of the master thesis. In the measure phase initial discussion with the stakeholders, the major problem with certain product and areas were identified and familiarization of the process, tools, and data collection platforms. As explained in the section 5.1.2 the stakeholders advised the authors to focus on certain products and historical data. The historical quality data with the production disturbance data were collected and compared. It was evident from the data that some disturbances are affecting and have a major impact on the quality of the product. Then a Value Stream Mapping (VSM) was collected from the stakeholders along with a detailed process map was drawn.

After certain investigations, and literature reading it was evident that classification and frequency of defects are necessary to focus since it's not possible to rank and find the root cause on a general perspective. Hence there were no recorded documents on the frequency and type of defects occurring a quality survey was conducted with various stakeholders to find out the most frequently occurring defects in both the products. Then fishbone diagram were drawn on each type of defect which the authors finalized to focus based on the survey results. In the initial cause and effect diagrams, we found that certain defects were due to lack of information flow and certain defects occur due to variation in critical process parameters.

Then further measured data were collected and investigated with various tools using scatter plots, histograms, descriptive statistics were calculated for the available data. Compared the data with two days a day when the products had the highest rejection and a day with low rejection to get a better idea. Which process parameter had major contribution to the defect on the highest rejection day. On further discussion with the focused group, literature study and the descriptive statistics results it was evident that these process can be controlled using statistical-based approaches. So the authors focused on both the measured data in terms of qualitative and quantitative data for further analysis. These measured data will be substantial to compare the data after the improvements are implemented and compare the results in the future state (Shankar, 2009).

In this context, a triangulated approach of discussion was carried with the focused group in the analyze phase. Then the authors used Fault Tree Analysis (FTA) to find the root cause for each defect based on the results from the measure phase and certain literature study. To be more clear about the process parameters a correlation analysis was carried out for the same population for both highest rejection day and lowest rejection day it was evident that some process parameter interdependencies on other machine parameters did not change on both the days were some parameters varied a lot. Based on the correlation result a regression analysis was carried to see whether the selected sample data can be used to predict the output to control the critical process parameters by controlling the input process parameters.

The fourth phase of the methodology is the improve phase. Based on the analysis and measure phase results certain improvements were suggested and explained in detail in the next chapter 6. Some improvements are in general to measure quality and structured data to ease the collection of measured data and focus more on analyze phase and improve the process or process optimization of critical parameters using regression analysis. To have good quality products (Kavade and Kadam, 2012) instead of using traditional software or charts provided by the material and machine suppliers. But these improvements have to be ranked and cost benefits have to be calculated in detail.

The last phase of the DMAIC process is to develop an action plan and monitor the solution in further work by developing work instructions and standardizing the process. Which the authors have not carried out because it's not possible to standardize the process without a physical test by doing improvements, testing and experimenting with the new solution. Since we had stated the limitation of no physical test will be conducted in this case study. We recommend to conduct Design Principle for Information Presentation (DFIP) to avoid error in achieving and developing a manual to solve quality-related problems in injection molding of plastic parts (Mattsson, Berglund and Li, 2016).

5.4 Research questions discussions

Answers to the research question that was developed during the master thesis are recalled from section 1.5 and discussed in detail keeping in context of the process steps that are required in finding and to optimize the critical parameters in the injection molding process. Both the results obtained from the case study and the theoretical study are focused along with the suggested improvements.

1.*How does the production disturbances affect the Quality of the product?*

When the number of stops in the production increase due to production disturbances the quality of the products decreases. Because each time when the production is stopped the machine takes a certain amount of time to get back to operate at standard machine process parameters. The initial parts, until the process is stabilized the produced, will have to be scrapped due to defects. Also, the correlation coefficient calculated by the authors for both the parts along with fault tree analysis which is presented in the previous chapters 4.2.1.2 and 4.3.2.2 helped us to give a better idea. Eventually, for this kind of manufacturing process, the production has to be more continuous with less number of stops as possible.

2.*How does information and production flow impact on the production disturbances?*

In this case study, there are many examples that the authors came across the information flow among various department are not as good. One such example will be explained here the planning department plans for the cycle time of 52 seconds one part has to be molded according to source shown in figure A.2 and A.1 but when the actual cycle time working on the shop floor calculated in the descriptive statics section table 4.5 it varies. This information from the RS production system (commonly known as the MRP system) and the injection molding machine data (commonly known as automation data) the difference is not updated in the planning system the IFS system (commonly known as an ERP system). The delay of nearly 4 seconds in each part makes a huge difference for the whole day which affects production planning. There might be an entry of the total number of parts produced by the end of the day and how much they are lagging behind the forecast. But this 4-second delay will lead to other problems in planning the forecast for maintenance and excess use of resources is unknown.

On the other hand, in this case, study they have a system for quality inspection of weight. Where sample parts are selected from a batch and weighted to know the stability of the process using a system called Rektron AB to verify quality inspections including the axial run-out and imbalance inspection in the Product A. The information from this system is also not shared with the IFS system (ERP system) when the weight of the part has increased the raw material and other resources utilization will increase. The raw material and other resources will fall shortage beforehand than the expected planed time. This kind of production disturbances such as shortage of material and etc cause stoppage's in the system. Therefore the information from each system is most important to avoid unnecessary production disturbances. How to improvise and needs for implementation for better information flow are suggested in chapter 6

3.*How do we balance the product quality and overall equipment effectiveness without hampering productivity?*

By making the suggested improvements in chapter 6 and investments to utilize the data captured in the organization. The proposed DMAIC methodology and tools to solve the quality (Lande et.al, 2016) related problem are more data-oriented. Hence it's very important to have good quality data which saves time in solving the problem as well as saves time in collecting data. when we compare their current method of solving the problem. There is no particular structured method involved in solving the problem and documenting the necessary data for reusing the knowledge that was involved in solving the problem previously. The most important part in this case study to control quality and overall equipment effectiveness can be done by optimizing the critical process parameters using the statistical approach (Kavade and Kadam, 2012) and regression analysis in such a way that it does not hamper the productivity of the process.

In this case study, the method the organization currently using for optimizing the process parameters were done using certain software's, control charts and based on their experience provided by the material suppliers and the injection molding machine supplier companies.

On the other hand, the suggested tools by the authors in this case study such as the descriptive statistics calculations, the regression analysis, and the correlation analysis take into consideration the machine and tools wear and tear. When a sample of data is chosen randomly to control the quality of the product at regular intervals for each batch. It's easy when its implemented and the quality control process is standardized. To predict the variations and control the process considering various factors affecting the quality this is most suitable according to the various literature study made by the authors.

4. *Why is the role of maintenance important on Overall Equipment Effectiveness(OEE) and product quality?*

"Maintenance of equipment is a necessary evil in today's world" (Maheshwaran, 2017). *"Since no equipment works flawlessly forever"* (Maheshwaran, 2017). The Overall Equipment Effectiveness (OEE), Mean Time to Repair (MTTR), Mean Time to Failure (MTTF) (Campbell 1995), (Maheshwaran, 2017), are the most important Key Performance Indicators (KPI) used in the industries. Since maintenance affects the productivity or the machine to perform with hundred percent stability it hampers the quality of the product.

When proper planning or documentation is not followed for maintenance, it directly or indirectly affects overall Equipment Effectiveness (OEE). In this case study, it was evident that certain quality defect such as burn marks usually occur due to accumulation of air and gas within the mold due to blockage of vents in the mold (Vyacheslav, 2018). When proper pressure and temperature sensors are utilized as suggested in the section 6.4 along with a prioritized maintenance system in the section 6.6 rather than doing maintenance after failure.

With documentation of Key Performance Indicators (KPI) such as Mean Time to Repair (MTTR), Mean Time to Failure (MTTF) will give better idea in implementing the prioritized maintenance system which in turn increases the availability of machine and mould, reduces quality-related problems, and increase production capacity (Maheshwaran; 2017). There are various proven study the authors have come across that maintenance leads to various problems and some such study result is as shown in figure 5.2. Also "15 percent to 70 percent of total production cost goes to maintenance activities from a study made in 2000 inherited from Muthu et al. 2000", (Maheshwaran; 2017). Hence the stakeholders of the organization have to consider in implementing them as suggested improvements.

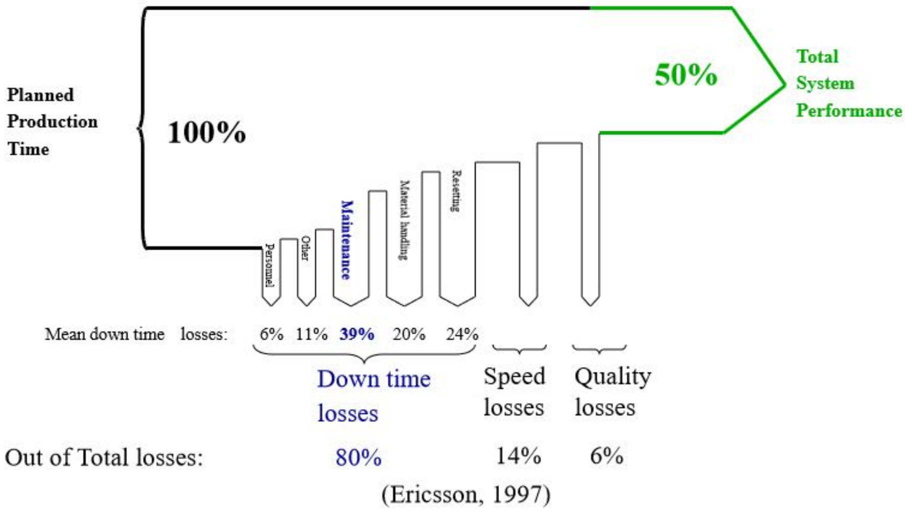

Figure 5.2: *Result from a case study taken from Ericsson, 1997 (Maheshwaran, 2017)*

5.5 Social Sustainability

In this master thesis, the authors conducted a case study in order to design an optimized method to solve quality-related defects and find its root cause in an injection molding of automotive plastic parts using Lean six sigma approach considering various improvement factors with a focus on quality. With the features of the DMAIC concept and six sigma tools in improving the method and finding critical parameters to solve the root cause of the problem in this master thesis has enabled the stakeholders in judging the critical parameters and improving the process using statistical tools.

These improvements were considered keeping human factors into account and able to carry out the process using technological assistance rather than doing it based on experience-based (Berlin and Adams, 2017). Thus the process of finding the root cause for the quality defect was made more socially sustainable keeping all the sustainable factors into consideration. So the stakeholders can carry out a healthy process aligned with by united nations World Commission on Environment and Development (WCED) (Bratt, 2009).

5.6 Further study required

As a part of the thesis, the stakeholders of the company should consider exploring further research they are

- In the current state, it was not possible to compare the quality measurement data from Rektron AB and critical machine process parameter data of the same product. Also, when there is a change in the batch of material does it affect the quality of the product and to find is there any correlation in the data.

- The critical process parameters such as melt temperature, mold temperature, injection temperature packing pressure, packing time, Injection pressure, has to be logged and correlation analysis and regression analysis should be carried out to get a better hold of the process performance.

- Today's fast-growing industrialized world there are a lot of new technologies such as AI-based controllers to automatically control the quality of the product based on the machine parameters and algorithms generated.

- The economical aspects were not addressed in depth by the authors the suggested improvements benefit both the quality of the product and time to solve the problem. Hence a detailed cost-benefit analysis has to be carried out.

6
Future Work Recommendations

This chapter describes the recommendations that Plastteknik AB should consider implementing.

6.1 Implementation of Bar Code On The Product

The problem with quality and sustainability in the production industries should not be focused on a single department but an entire process. In order to be able to easily track any problem within the production unit, tracking of the product from beginning to the end of the process is a basic requirement.

At Plastteknik AB, the only product marking that was followed during production was the date, month and year of production. Implementation of bar code on the products carrying information such as a batch of raw material used, machine parameters during production and testing will make it easier for further and accurate analysis whenever a problem is encountered. Trace-ability of products should be considered as a basic requirement in manufacturing sectors.

6.2 Centralized Monitoring System

Even though every department has adopted systematic way of working at Plastteknik AB, the communication between the departments was lagging. In order to counter this problem, a Centralized Monitoring System should be adopted which interlinks different departments within the company and avoids miscommunication within the department.

As shown in the figure 6.1 (J.Kletti, Springer 2007) implementation of Centralized Monitoring System such as MES (Manufacturing Execution System) will make it possible to assign really specific fields of action to the three levels of corporate management, production management, and production. Real-time visibility for real-time management will then be a reality in the manufacturing sectors.

With the implementation of Centralized Monitoring System, each department will have easy access to the required information from the other department within the company whenever required. For example, when you consider planning department in order for it to function smoothly and efficiently without any fault, planning department needs information from most of the department raw material handling, logistics, sales, purchasing and production which will be made possible with the help of a Centralized Monitoring System.

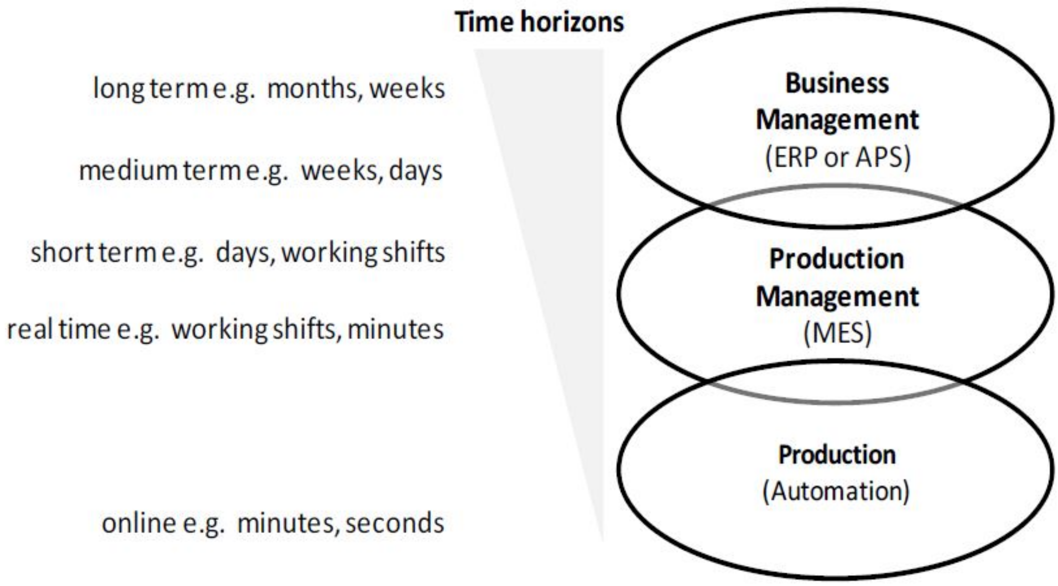

Figure 6.1: *MES with in the company*

6.2.1 Implement Optimized, Long Production Runs Without Interruptions

Rejection due to start-up part was one of the major problems with Product A. Once the machine is restarted it would take some time to become stable, by the time machine became stable some products would be rejected since the quality of the products is not up to the mark. So, in order to reduce this rejection percentage of start-up parts the machine stops must be reduced and have an optimized, long production runs without any interruptions.

This does not mean that production run should be pushed over the limit, which could damage the machine or the mold. The maintenance of machine, mold and production runs should be balanced in such a way that the stoppage in production runs for maintenance does not contribute to the rejection percentage of start-up parts and long production runs do not affect the quality of the mold or the machine.

As the authors have also discussed more in detail about the benefits of having a centralized data system in the previous chapter under the section 5.4 research question number 2. This mentioned improvement helps the planning department in a much better way to have a well-balanced production system.

6.3 Quality check of raw materials

Quality check of raw material is carried out in the initial production phase in terms of the moisture content but its neglected when it comes to the composition purity and granule size. Since the purity of raw material and raw material granule size make an impact on the quality of the product, we recommend that raw material quality check in terms of purity or composition of raw material and granule size is checked on a frequent basis.

This step might be required to have good trace-ability of the products. Also, If we find evidence that when there is a change in the batch of material the process parameter varies and deviates more than the normal and if we find quality defects in the product this might be necessary. Since the authors could not trace this evidence during their case study. when there is a change in the batch of raw material does it hamper the quality of the product?

6.4 Using Dies With Pressure Gauges and Temperature Sensors

During the data analysis phase, we realized that some of the critical parameters such as melt temperature, tool temperature and pressure within the mold were not captured. Advanced tools with pressure and temperature sensors would make it possible for the production team to capture those data, which can be frequently analyzed to control the quality of the product (Kumar et al, 2019). There are many findings from many researchers (Alireza Akbarzadeh and Mohammad Sadeghi, 2011), (Kumar et al, 2019) and (Kavade and Kadam, 2012) that measuring them can help in controlling the quality of the product using the statistical methods.

Dies with pressure and temperature gauges will make it possible for the production and quality department to track and analyze the problems much better. Which would mean that accurate and quality data will be available for the quality department to tackle the problems using the proposed DMAIC method and tools shown in figure 3.1. If there is fluctuation in current that will lead to temperature variation of the melt.

On the other hand, the injection time is the most important parameter to control the quality of the product from various literature findings (Kavade and Kadam, 2012) 3.3. In the equation 2.1 suggested by Bown, 1979 (Whelan, 1982) to calculate the injection time we can see that the temperature of the mold and the temperature in the cylinder are inversely proportional to the injection time. When there is an increase in the temperature the injection time decreases hence it's important to measure the temperature to have defect-free products and control the process.

6.5 Consistent Logging of Machine Data With Suitable Critical Parameters

Logging of machine data was done with the help of an external USB device, where every time they plugged in the USB device and the person in charge would select the required parameters that need to be logged. But this type of data capture was not consistent enough to be able to carry out a qualitative analysis with the data available. In addition to that, it was evident that the parameters selection was randomly done without prioritizing the critical parameters.

If the data collected is not trusted worthy or insufficient, it may lead analysis to a wrong path and consume more time in collecting, sorting and filtering the data. So, it is recommended that consistency in logging the critical process machine data during the production phase and along with that selection of suitable parameters that needs to be logged. In injection molding, there are several parameters affecting the quality of the product, so it is necessary that suitable parameters are selected for data logging based on the cause and effect diagram for each type of defect.

6.5.1 Statistical analysis

We authors recommend the stakeholders to conduct statistical-based analysis to predict the failures since it was evident from the results obtained in this case study shown in section 4.2.5. If the critical parameters are logged and descriptive statistics are calculated by collecting samples from the population the variation of certain critical parameters can be predicted from the statistical results to have control over the process. Similarly, the critical parameters that affect burn marks in the product which is caused due to air trap in the mould can be predicted with pressure sensors in the mould and measuring it and based on statistical approach when it crosses certain limit the information can be sent to the maintenance department in advance to be prepared for repair work.

6.6 Implement Prioritized Maintenance System

Maintenance department follows a set of rules and checklist for maintenance of dies and machines. But with the shortage of manpower in the maintenance department, it will be hard to focus on every aspect of the problem. So, in order to systematically manage the maintenance of dies, it is recommended to prioritize the maintenance process with proper planning and strategies according to the problems faced during that period of usage of mold before it is taken down for maintenance.

For example, considering major problems faced with carrier plate: burn marks and cracks. The production team could intimate the maintenance department that they are facing the problem with these defects in particular so that the maintenance department could prioritize accordingly the checklist for maintenance of die, such as looking for the blockage of air vents and then following it up with the general maintenance of the die.

6.6.1 Maintenance of Dies As Per Schedule

Dies are taken down for maintenance after a certain number of shots (Number of products produced). During the project phase, the project team and the die makers set the number of shots that particular die can take before it is taken down to maintenance. In the case of Product A, the tool must be taken down for general maintenance after 10,000 number of shots and for maintenance of cooling channel after 1,50,000 number of shots. Whereas in case of Product B, the tool must be taken down for general maintenance after 20,000 number of shots and for maintenance of cooling channel 90,000 number of shots.

Even though the number of shots taken by the die is monitored, the shots limit are being crossed. That means the tool is not taken down for maintenance after the tool has reached its limit number of shots. This should be avoided in order to maintain the quality of the die and to carry out maintenance in a systematic manner.

The authors have also discussed the importance of why the maintenance is to be carried out in a systematic manner in previous chapter section 5.4 question number 4. By using the pressure and temperature sensors explained in the section 6.4 we can predict the amount of blockage of vents in the mold by logging the data Since we know that these blocks are caused due to hot air and gas getting trapped inside the mold (Vyacheslav, 2018).

6.7 Introducing Quick View Screens

In order to track and analyze the problem, better data collection is a necessary requirement. To be able to achieve this we would like to recommend Quick View Screen. As shown in figure 6.2 Quick View Screen will make it possible to store information on the type of defects. In addition to that, it will be possible to see the rejection percentage in the last hour, 24 hours, previous shift and ongoing shift.

Top three defects will also be reflected in the screen. Automatic notifications can be generated based on the rejection percentage and the limits set. Rejection percentage range can be set to the three colors green, yellow and red. Whenever the quality meter enters the yellow or red zone, then automatic notifications will be sent to the in-charge person which will make it possible for them to take actions immediately. The action taken by the manager or the person in charge will be made visible on the screen as shown in figure 6.2.

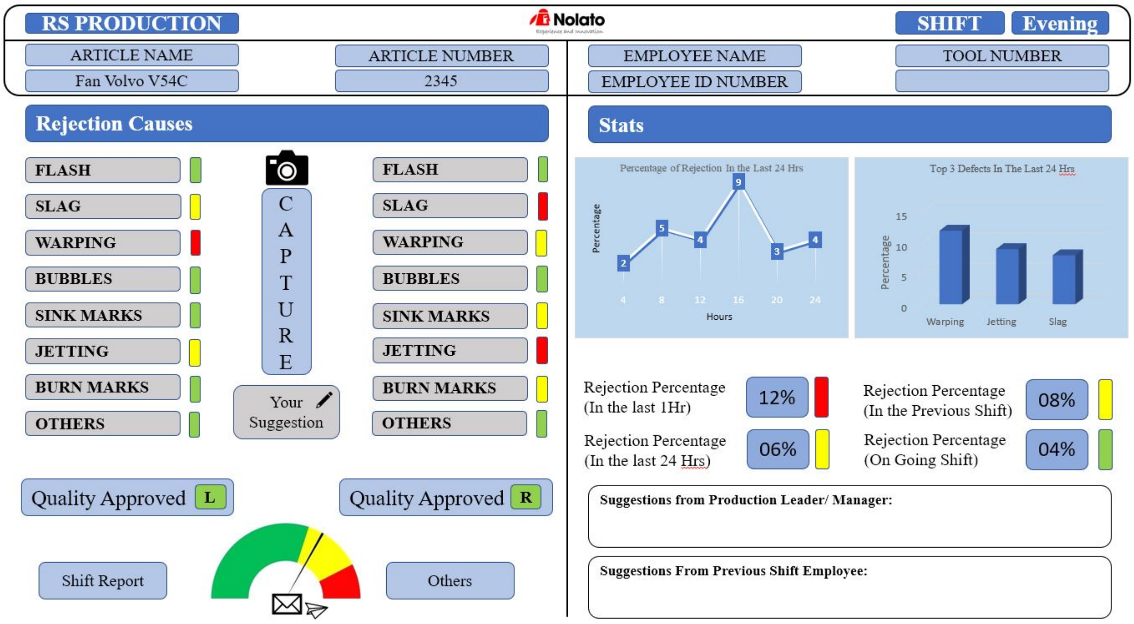

Figure 6.2: *QuickView Screen01*

The operator can leave comments for the next shift operator as shown in the figure 6.3, which will be useful for the next operator as he will know as to what to expect working on that machine and tool.

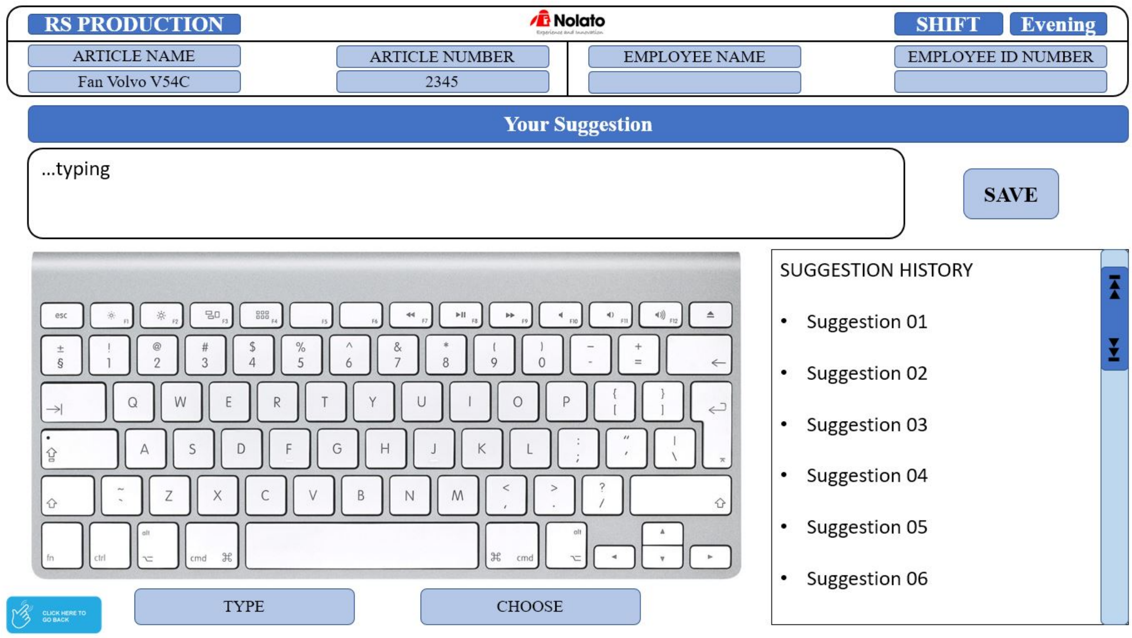

Figure 6.3: *QuickView Screen02*

As shown in figure 6.2, the defect image can also be captured, which can then be used by the production and the quality team for further analysis. The images stored can be accessed by the person in charge as shown in the figure 6.4, with the details of the date, time, shift and batch number of that particular product.

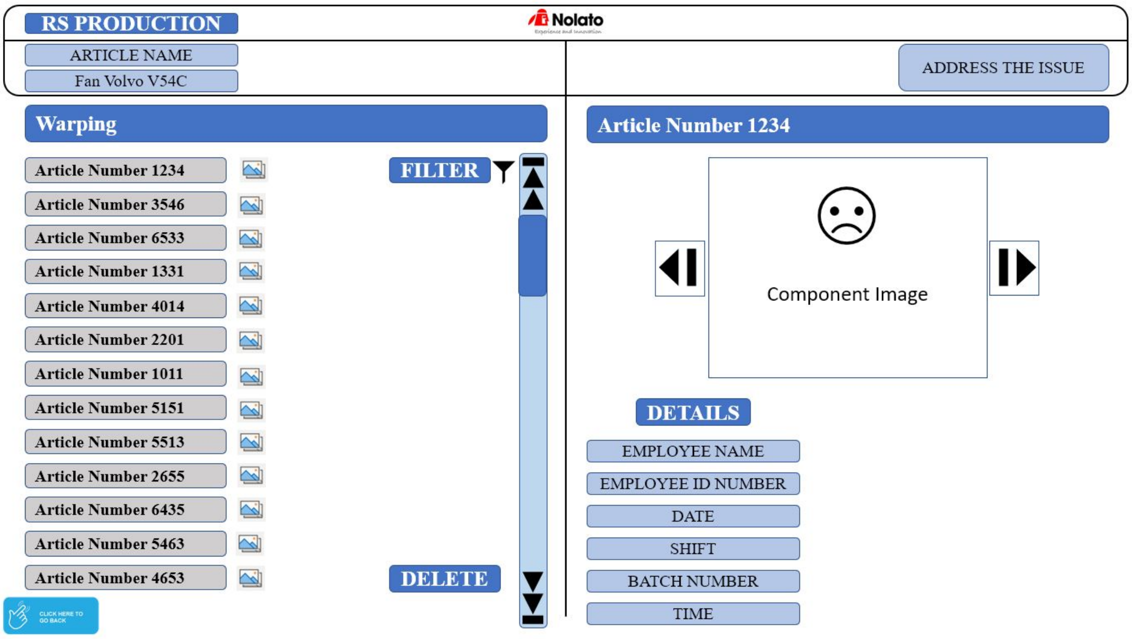

Figure 6.4: *QuickView Screen03*

Capturing data in a systematic way is beneficial, but will be of no use if it's not analyzed and assessed regularly. So, once the data is captured it must be analyzed and causes and remedies must be documented as shown in the figure 6.5. Only after the analysis and documentation of analysis, caused and remedies the images of the defects of that quarter can be deleted from the database.

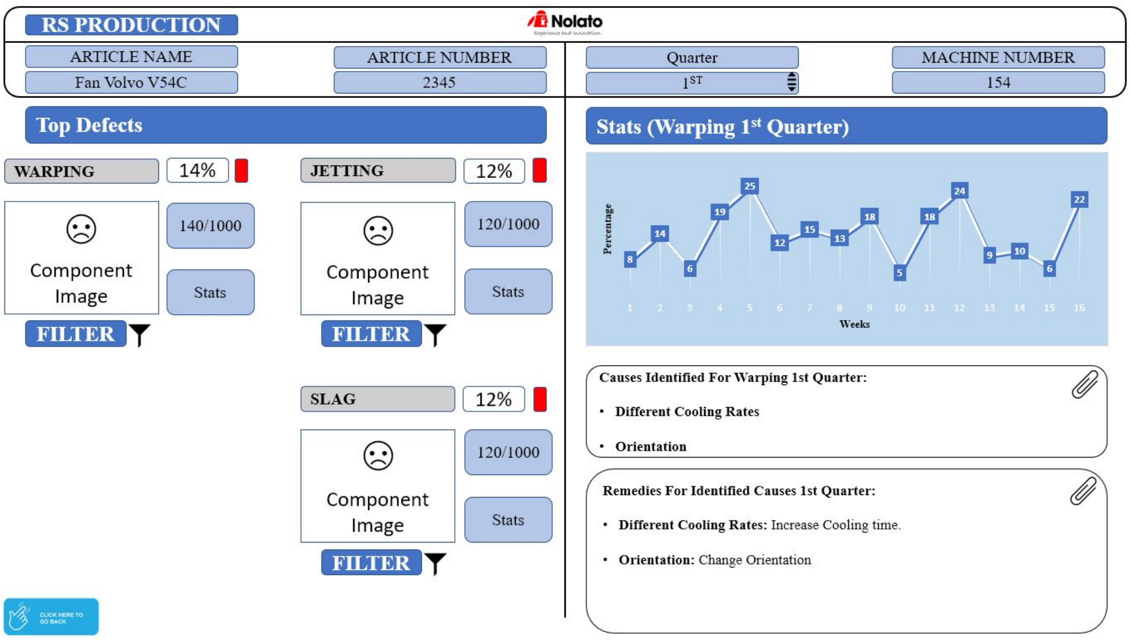

Figure 6.5: *QuickView Screen04*

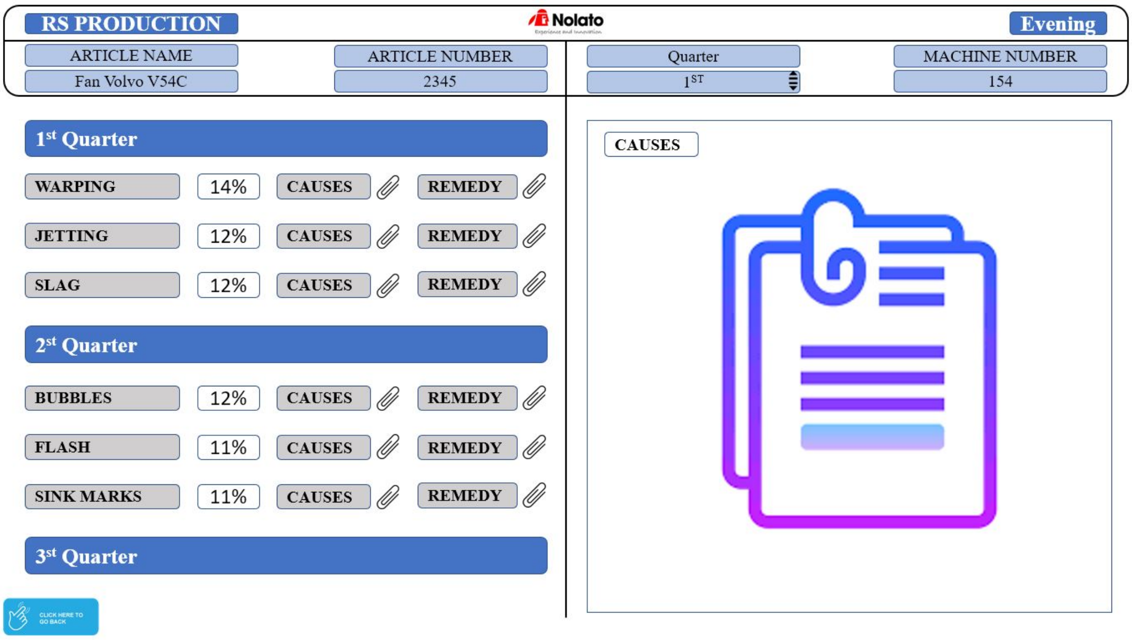

Figure 6.6: *QuickView Screen05*

The causes and remedies that were documented will be available in the database for access as shown in the figure 6.6. With the help of these historical data, it will be easier to tackle and find a solution to the quality problem.

This is a conceptual screen designed and modeled basically to track the frequency of the defects occurring and to have the quick view of the critical process parameters are within the estimated limits. If not sample data can be collected and used to calculate the descriptive statistics along with correlation and regression analysis to see the interdependence's and predict on each critical parameters and to control back the process back to the normal stage.

If the above-mentioned calculations have to be done on a random sampling-based to save time and cost size should be at least 0.55 percent of the total sample of the population produced in the batch according to the (ASTM and HMSO) standards (Whelan, 1982). The advantage of using this method is already discussed in the previous chapter section 5.4 research question number 3. Which takes various factors into consideration in optimizing the process parameters.

7 Conclusion

This chapter illustrates conclusive remarks of the thesis work.

From the discussion on how the quality problem was tackled and why the achieved results were obtained, it can be said the authors have satisfied the purpose of this thesis and helped Plastteknik AB to tackle the problem with respect to quality and sustainability. There were few very important recommendations which if implemented could bring positive changes to the system and would help them tackle the quality problem much better.

In conclusion here are the highlights of this master thesis study.

Research findings

- It was evident in this case study that production disturbance affects the quality of the product by 50 percent in Product A and 38 percent in Product B in terms of stops caused by the disturbances which exclude planned stops.

- The information flow and types of flow (ie.Digital electronic flow of information, by means of paper), across various departments and levels in the organization have an impact to predict the disturbances that affect the quality of the product when it comes to traceability of the product and the process.

- The proposed DMAIC methodology which various tools have helped to analyze the problems to balance product quality along with Overall Equipment Effectiveness (OEE) without hampering the productivity.

- , In this case, study the authors found that a proper maintenance strategy and planning is essential to perform maintenance for the machine as well as mold since lack of maintenance affects the performance and quality of the product which in turn affects the Overall Equipment Effectiveness (OEE) of the organization.

Other findings

- Though Fault Tree Analysis model indicate the root cause of the problems, machine data analysis results indicate still there is room for improvement in the maintenance department.

- Economical aspects of sustainability have been addressed by suitable recommendations for each defect.
- It is possible to improve the product quality by reducing the production disturbance and Impact of production disturbance on product quality had been discussed in quality data analysis.
- Role of maintenance on overall equipment effectiveness and product quality addressed through fault tree analysis and regression analysis.
- If future work recommendations are implemented, Plastteknik AB can monitor, and tackle problems related to quality in a better way.
- Importance of data collection on product quality has been addressed in the future work recommendations.

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A

Appendix 1

A.1 Planning report

1 Introduction

Master thesis is being performed at Plastteknik AB which aims at reducing the production disturbances to enhance quality, production performance by keeping sustainability factors into consideration. It focuses on identifying and analyzing the root cause factors that are responsible for the production disturbance which affects the quality of the products.

The thesis is based on the production service and maintenance system, which will be performed by two students under the master's program Production Engineering.

2 Background

Today's productions system are more focused on being resource efficient to achieve high productivity with flexibility (Jon Bokrantz et al., 2016). Even with a strong commitment to production and maintenance personnel companies have failed to improve the performance in terms of overall equipment effectiveness (OEE). Which has pressurized the companies to minimize the production disturbances that cost Swedish manufacturing industries billions of Swedish kronor per year (Jon Bokrantz et al., 2016). However, recent technologies and software have made it possible to gather the data from the machines on a regular basis, which can be used to analyze the disturbance pattern.

The companies have carried out various researches in identifying the parameters that affect product quality and production performance. Production disturbance affects overall equipment effectiveness, which directly hampers quality and production performance. Production disturbance has proved to be a major thorn in the production performance which affects quality, decreases productivity, increase product cost and reduces profitability (Jon Bokrantz et al., 2016).

The current project involves analyzing qualitative and quantitative data to find a disturbance pattern which will eventually lead us to the root cause of the quality problem. When further analyzed in-depth could lead us to a suitable and feasible solution. The encountered problems can be utilized to achieve products of the highest quality.

3 Aim

The main objective of the thesis is to investigate the root cause of production disturbances at Plastteknik AB that is responsible for the product quality. Various qualitative and quantitative methods are implemented to assess overall sustainability impacts of production disturbances..

4 Limitations

- We are focusing on two products Product A and Product B which are having a major quality issue at Plastteknik AB as mentioned by the company personnel.
- We will be focusing on production disturbances that affect the Quality of the products.

- We are not going to carry out any destructive or non-destructive testing (NDT) of products.

5 Specifications of Issue Under Investigation

- How does the production disturbances affect the Quality of the product?
- How does information and production flow impact on the production disturbances?
- How do we balance the product quality and overall equipment effectiveness without hampering productivity?
- What is the role of maintenance on Overall Equipment Effectiveness(OEE) and product quality?

6 Methodology

In this thesis, we are going to have applied research on the production disturbances at Plastteknik AB where we are going to analyze the real-time situation to find the root cause of the problem. In this case study, we are going to have both qualitative and quantitative data analysis with the help of empirical evidence that we gather at Plastteknik AB. The methodology that we have planned of implementing in our project is as shown in the figure 1. Along with this to have a better analysis of the gathered data, we will be implementing the triangulation method, which is illustrated in figure 2.

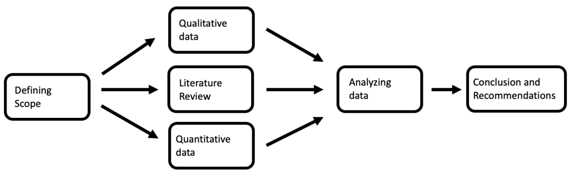


Figure 1: Visualization of how the triangulation Method validate the gathered data

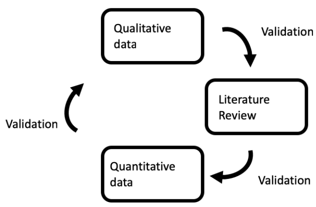


Figure 2: Visualization of the methodology that was used during the project

For problem-solving and to improve the process we are using the DMAIC approach which would eliminate the inefficiencies in a system by improvising and stabilizing the system, which is illustrated in the figure3.

Figure 3: Define,Measure, Analysis and Control

For the root cause analysis, we will be using FTA(Fault Tree Analysis) which will give us a better understanding of the of the problem and would help us to find the root cause of the problem, an example of which is illustrated in figure4.

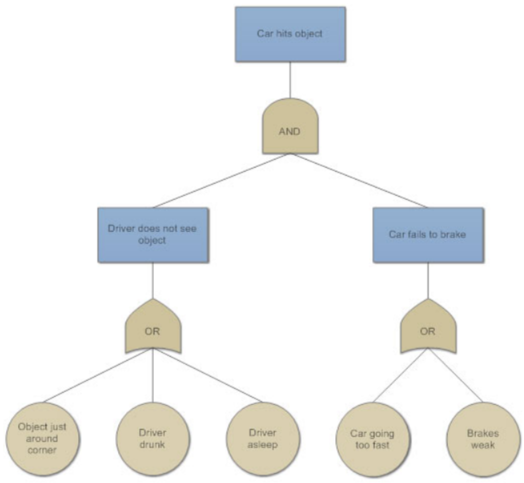
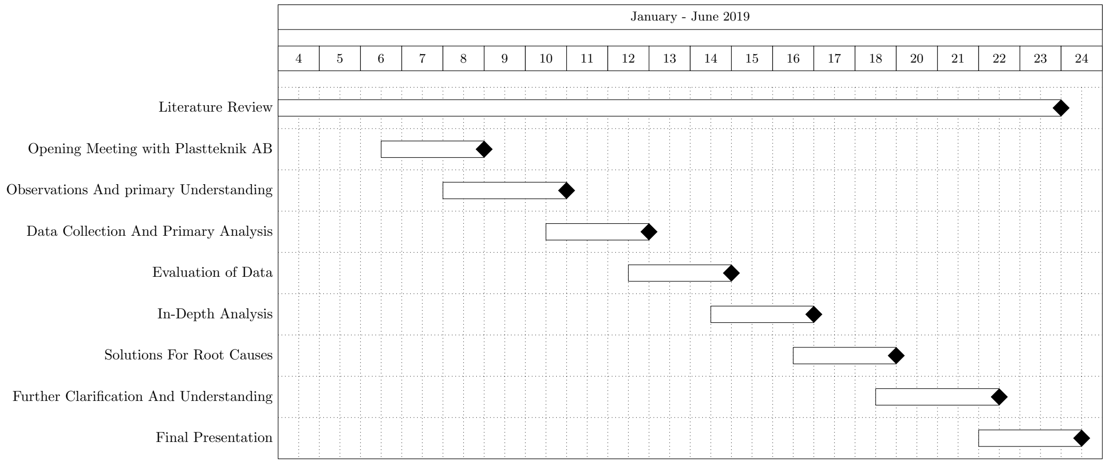


Figure 4: Define,Measure, Analysis and Control

7 Schedule



In order to have an overview of the time plan for each task have made use of the Gantt chart, which will be updated and referred accordingly.

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8 Appendix

Interview protocol and the questions for different departments are listed below.

- How does the production disturbances affect the Quality of product?

  i. Could you briefly explain how Quality Assurance Department operate while inspecting Product A and Product B?

  ii. Problem with quality of these two products were identified from the beginning (I mean from the day you started producing those products) or in the recent years?

  iii. Could you list the major defects in those two products?

  iv. What actions were taken in order to reduce those defects?

  v. What was the results of your efforts or action?

  vi. Is the quality of the raw materials inspected before being used?

  vii. What percentage of products (Product A and Product B) are sent back from the customers because of the quality issues?

- How does information and production flow impact on the production disturbances?

  i. Could you briefly explain how Production Department operate while producing Product A and Product B?

  ii. How do you plan production and resources for Product A and Product B?

  iii. From how many years are you producing Product A and Product B?

  iv. Machine identification numbers for products Product A and Product B.

  v. Are any other products produced in these machines?

  vi. Is there any tool identification, to identify this product was produced in this tool?

  vii. Are the operators aware of the kind on defects occurring in Product A and Product B?

viii. Were there any suggestions from the operators to avoid these defects? If yes, what did they suggest?

ix. Quantity/weight and composition of raw material that goes in to the machine to produce Product A and Product B?

x. How many products are produced at a time? How many in an hour?

xi. Is production single piece flow or batch production? If in batches what's the batch size?

xii. How often do you train the operators and the methods used for training?

- How do we balance the product quality and overall equipment effectiveness without hampering the productivity?

- What is the role of maintenance on Overall Equipment Effectiveness(OEE) and product quality?

i. Could you briefly explain how Maintenance Department operate while doing maintenance on machines and tools that produce Product A and Product B?

ii. Do you face the same issues or problem (wear and tear) with the machine while doing maintenance or is it different every time?

iii. Frequency of maintenance or how do you plan maintenance?

iv. Could you list the major problems identified in machine during maintenance and how it was addressed?

v. How frequently tools are changed? Major reason for tool change?

A.2 Value Stream Mapping

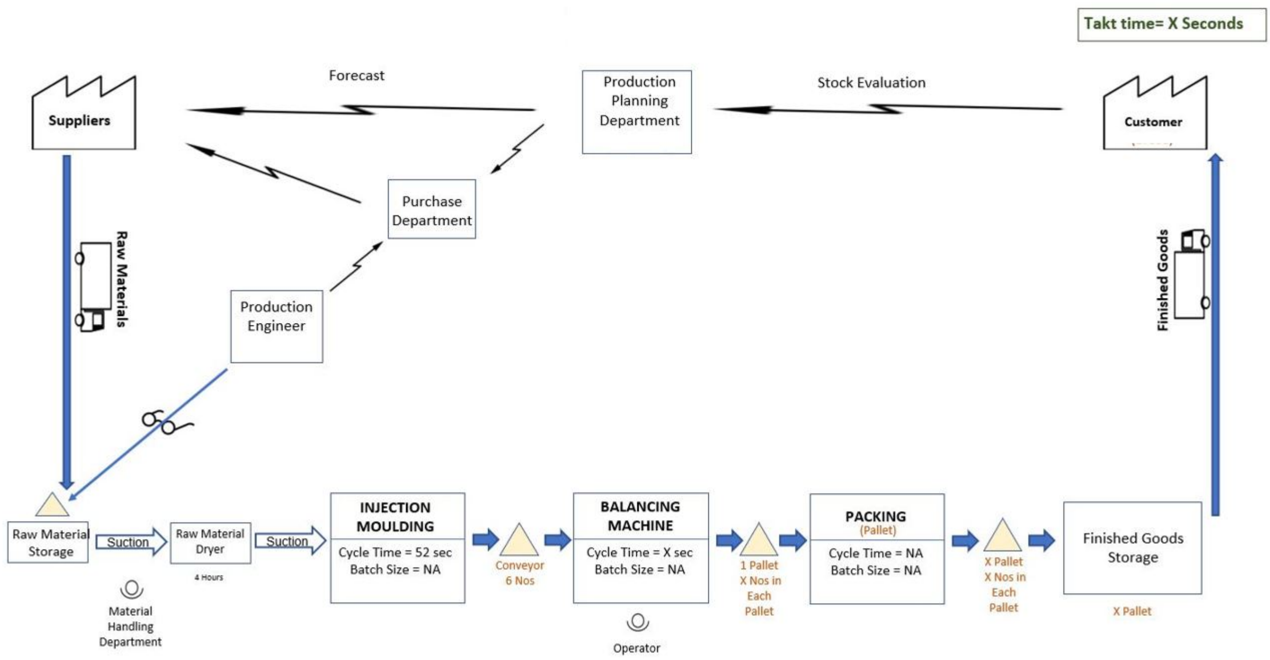

Figure A.1: *Value stream map (VSM) of Product A*

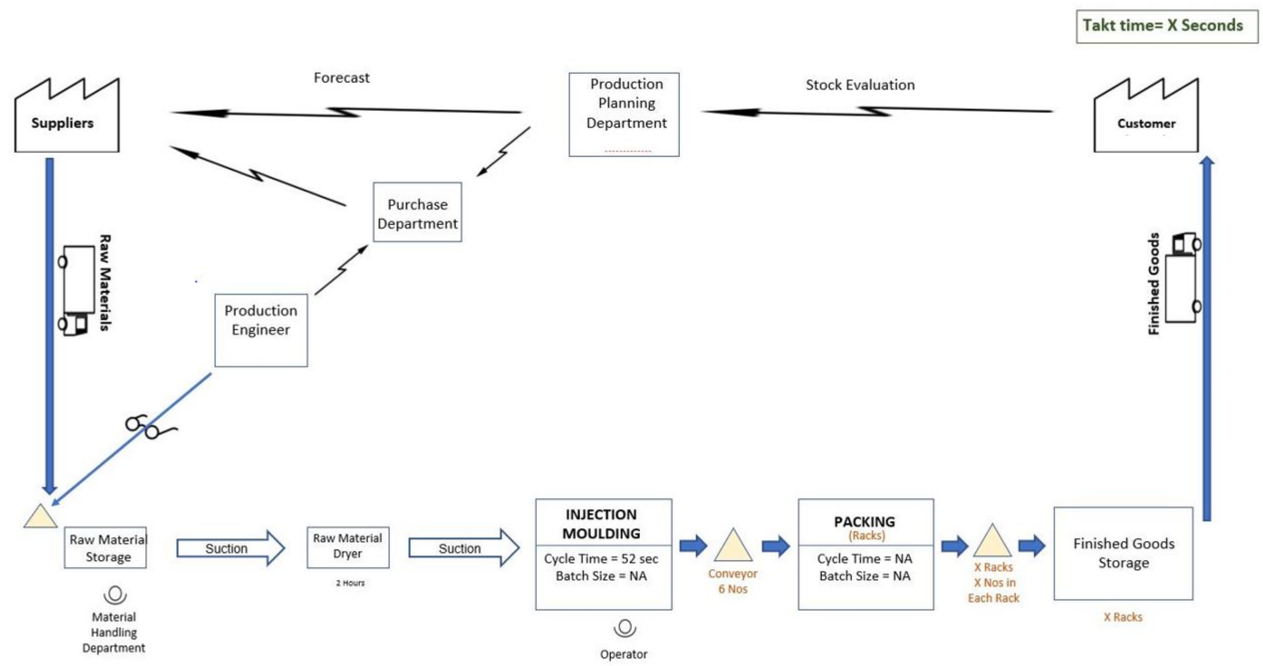

Figure A.2: *Value stream map (VSM) of Product B.*

A.3 Machine Log Data

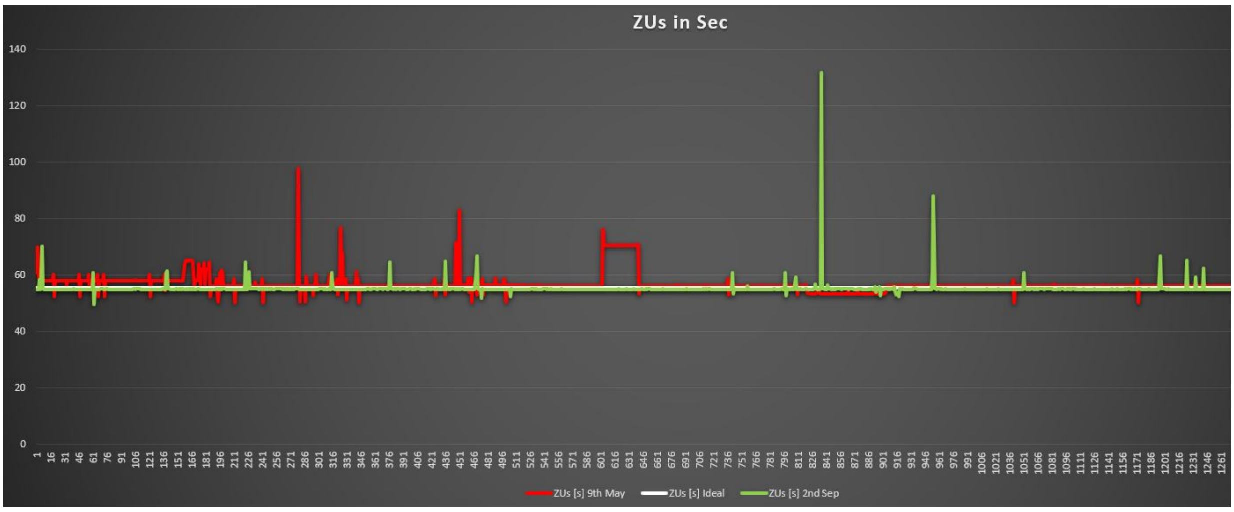

Figure A.3: *Machine Log Data ZUs in Sec: Product A*

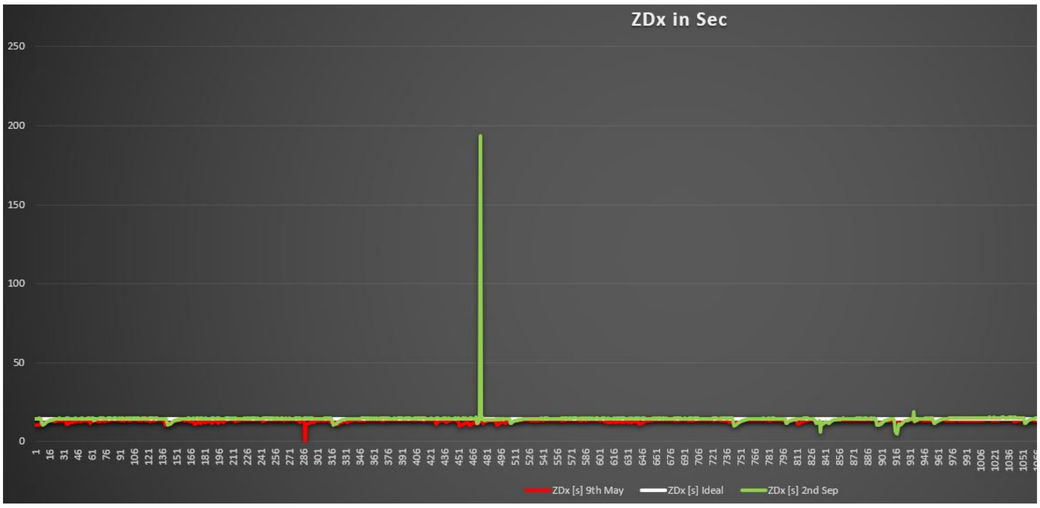

Figure A.4: *Machine Log Data ZDx in Sec: Product A*

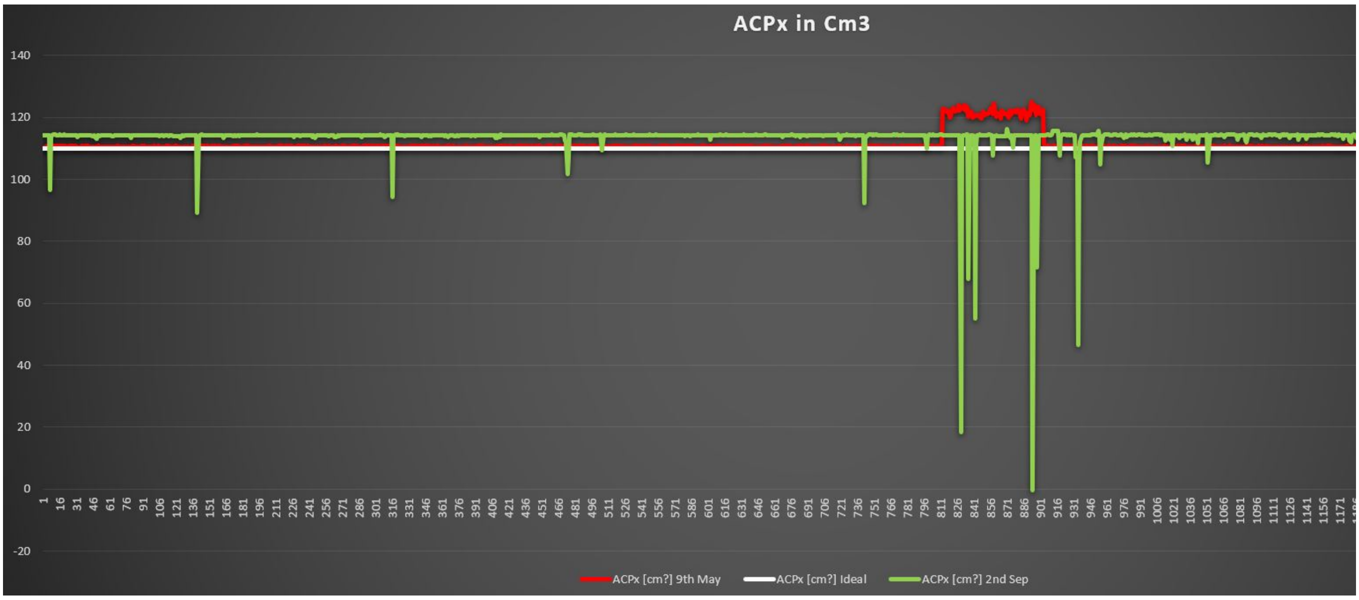

Figure A.5: *Machine Log Data ACPx in Cm3: Product A*

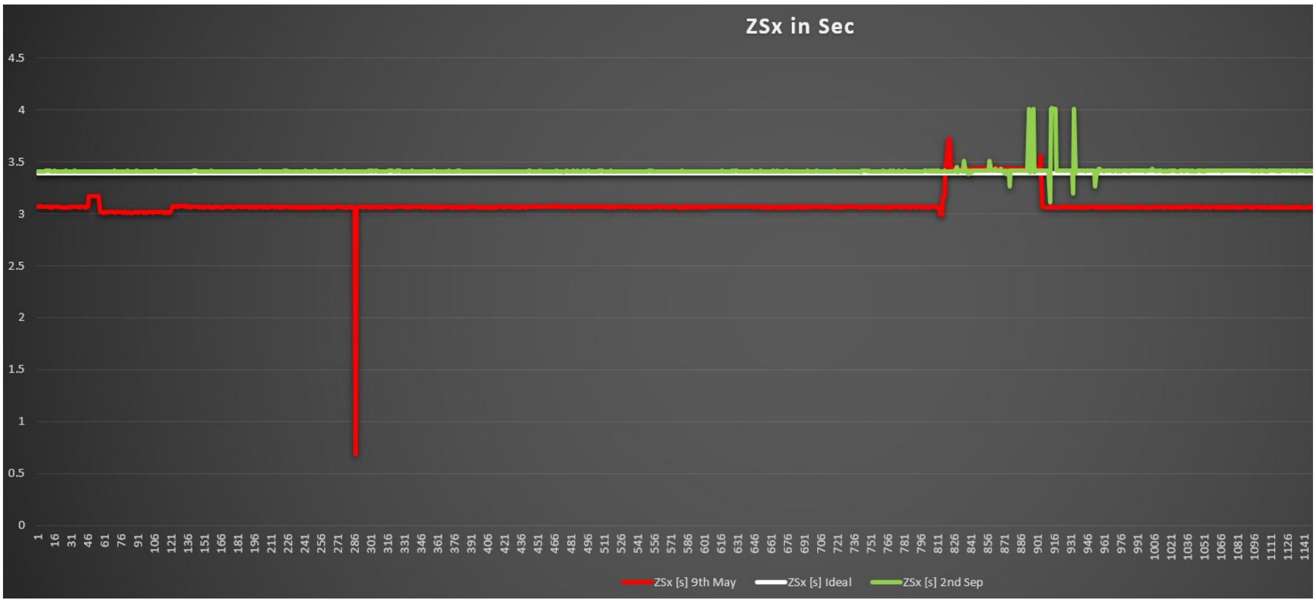

Figure A.6: *Machine Log Data ZSx in Sec: Product A*

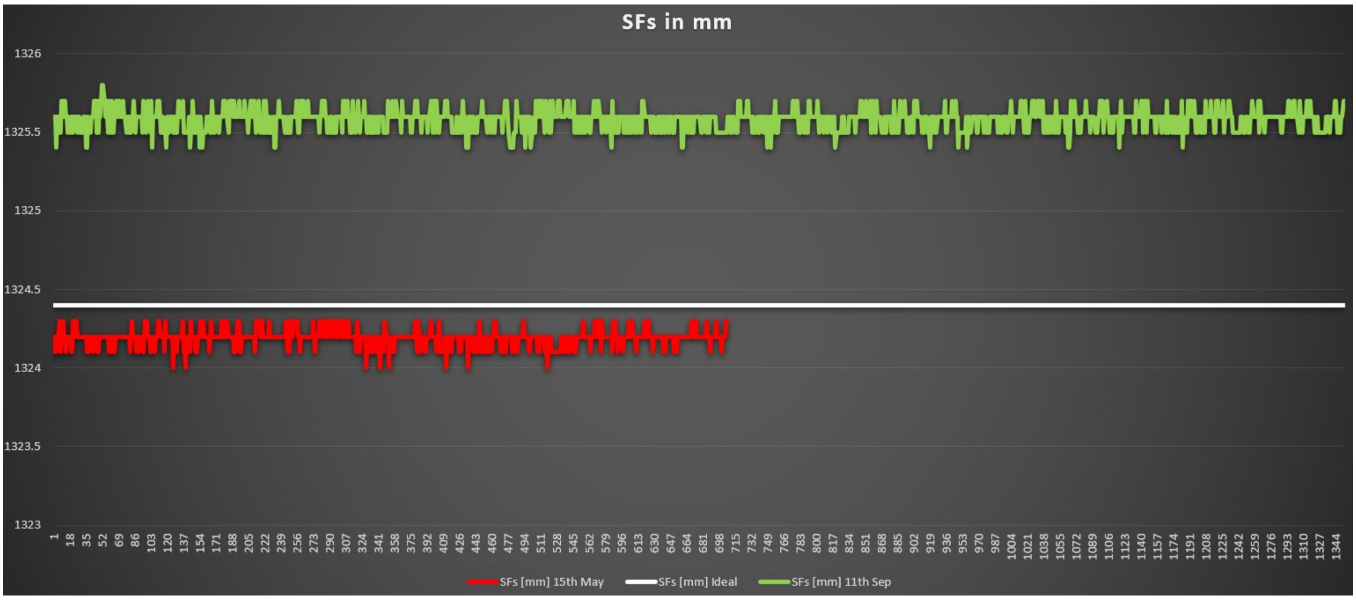

Figure A.7: *Machine Log Data SFs in mm: Product B*

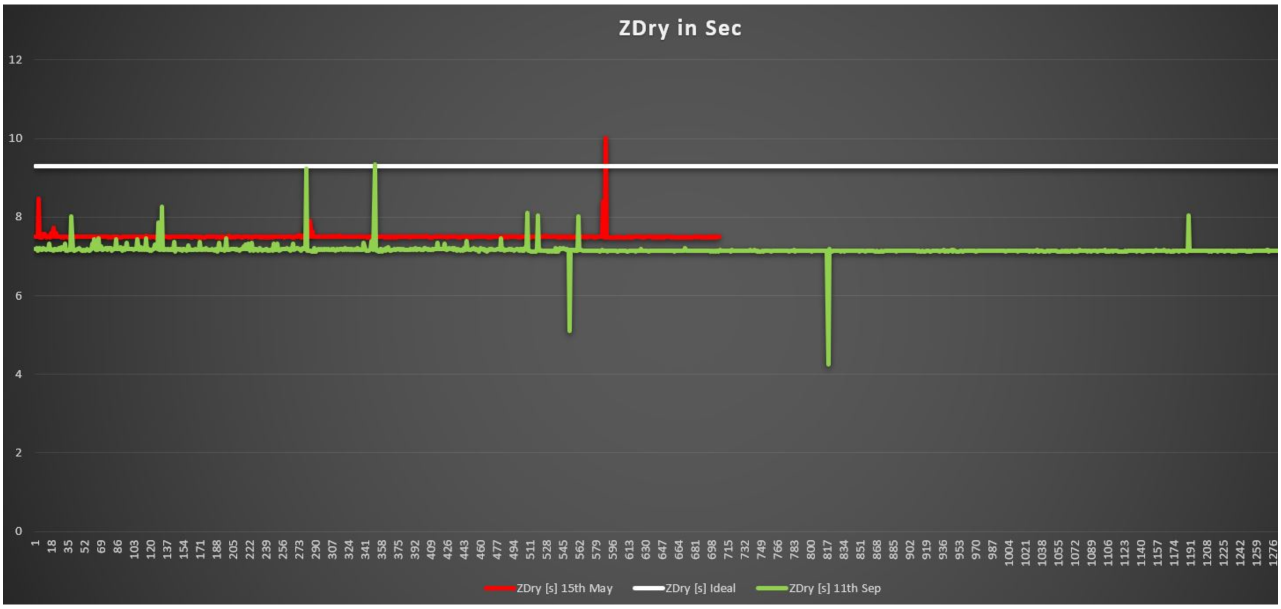

Figure A.8: *Machine Log Data ZDry in Sec: Product B*

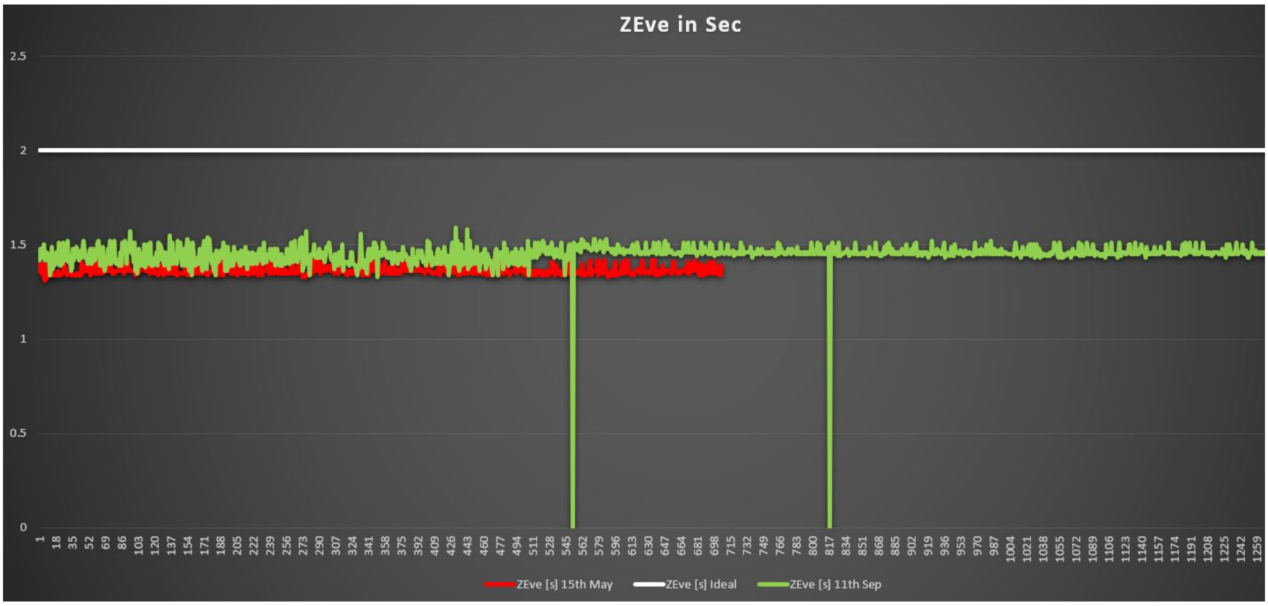

Figure A.9: *Machine Log Data ZEve in Sec: Product B*

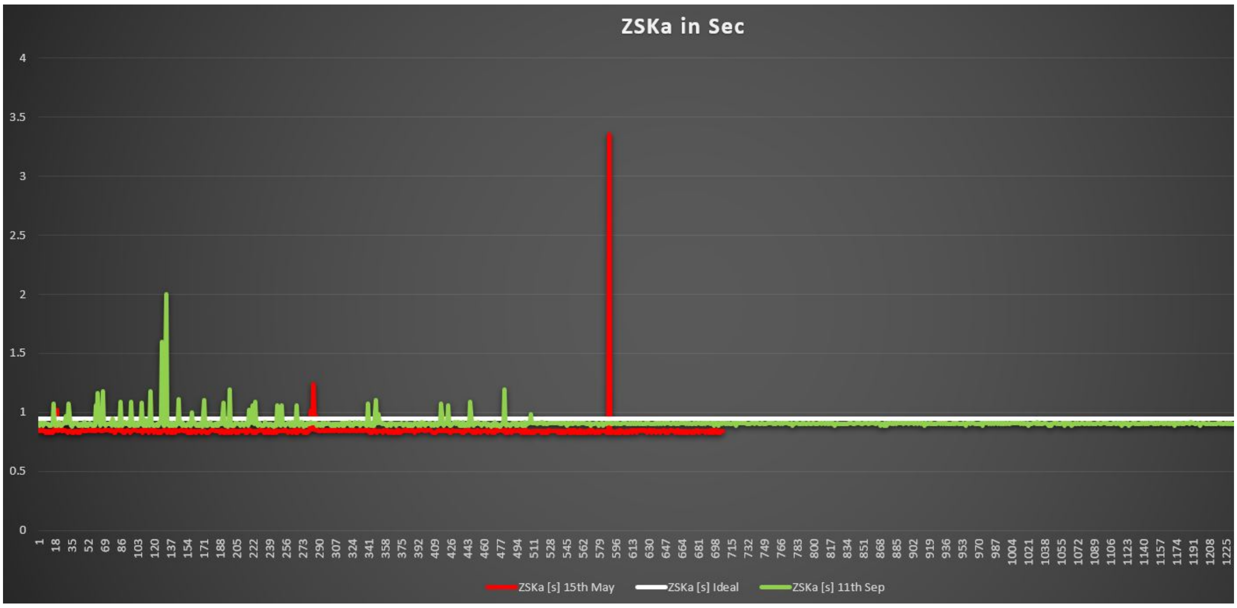

Figure A.10: *Machine Log Data ZSKa in Sec: Product B*

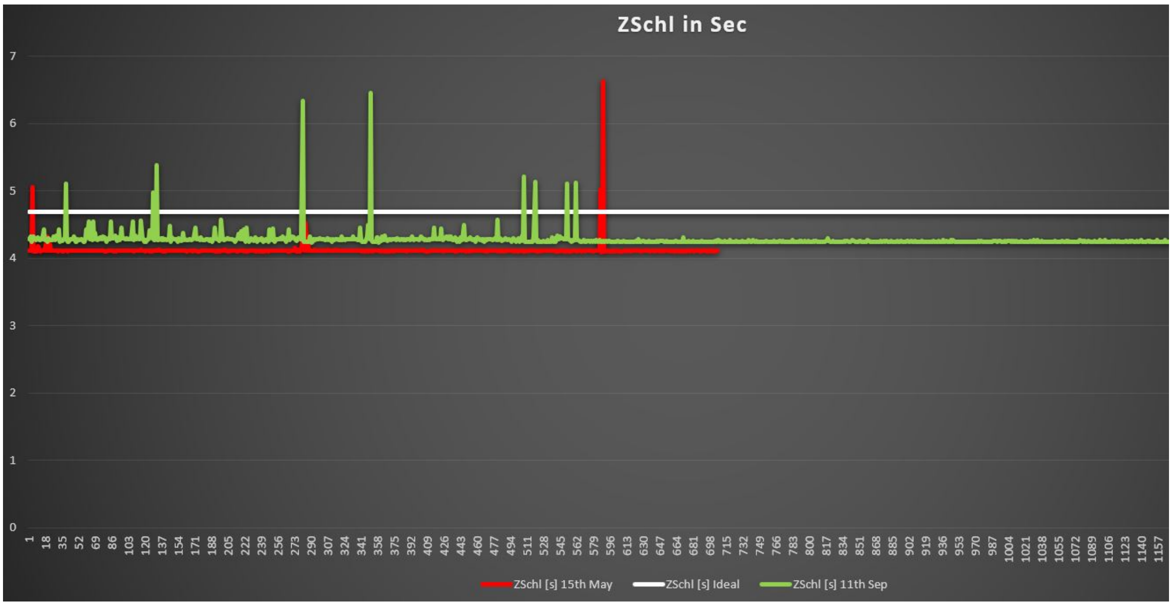

Figure A.11: *Machine Log Data ZSchl in Sec: Product B*

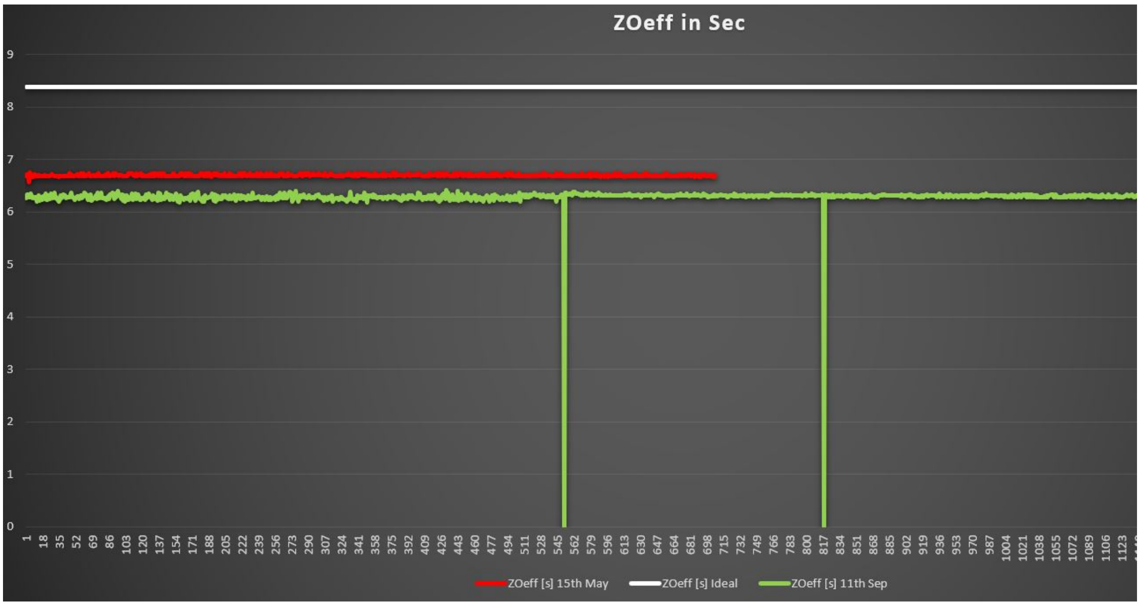

Figure A.12: *Machine Log Data ZOeff in Sec: Product B*

A.4 Fishbone diagram for defects

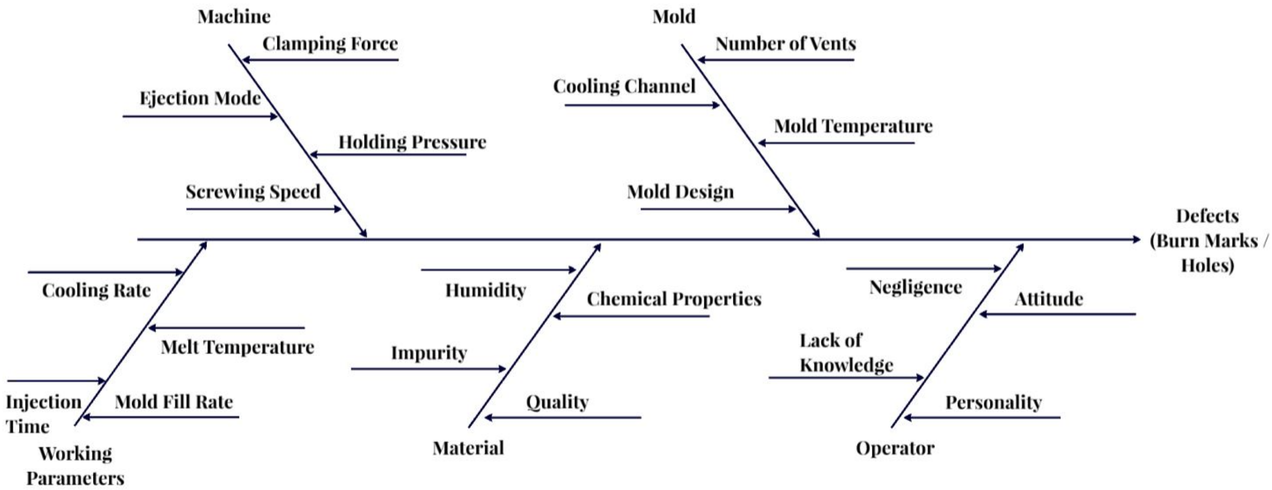

Figure A.13: *Fish bone for burn marks*

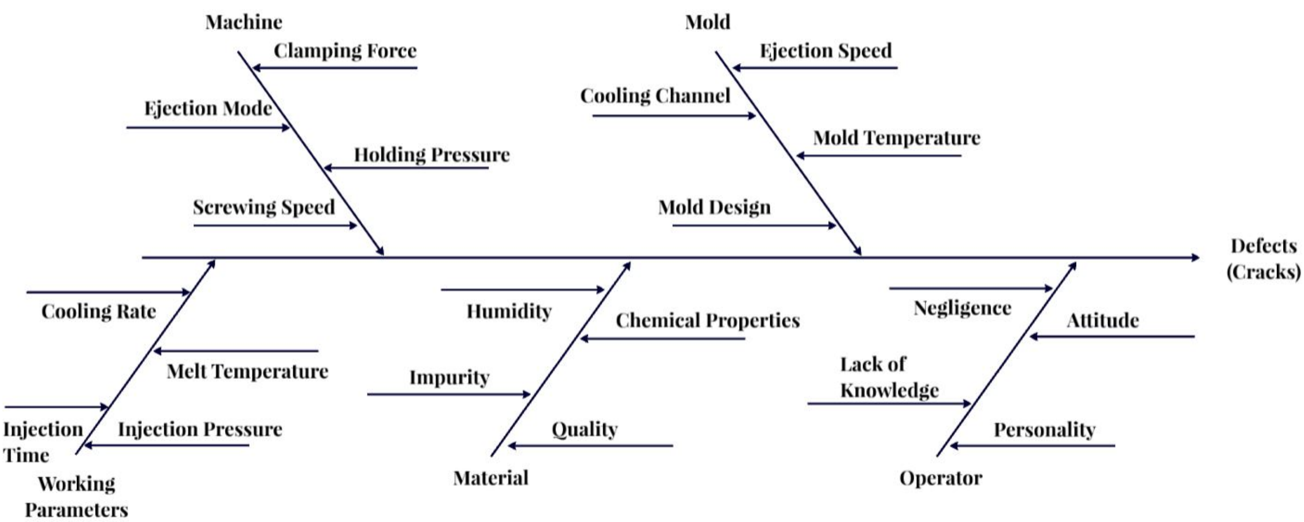

Figure A.14: *Fish bone for cracks*

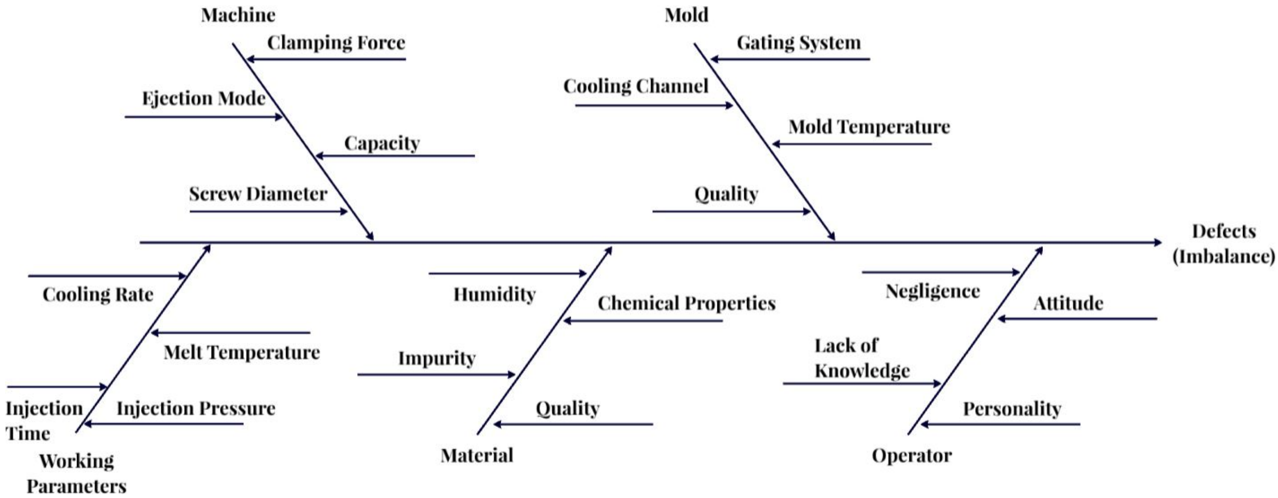

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Figure A.15: *Fish bone for Imbalance*

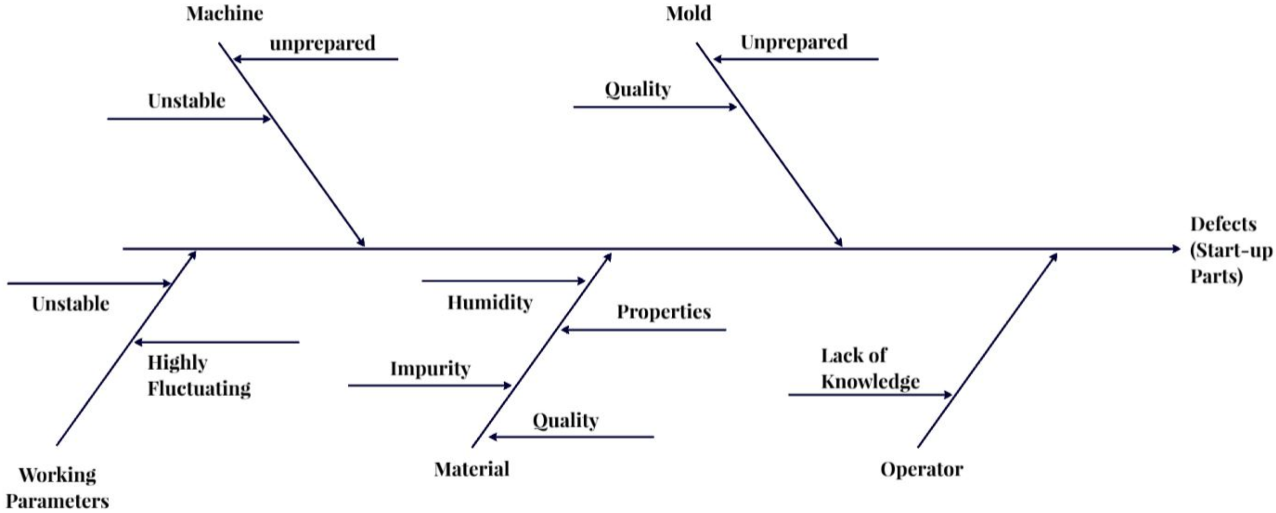

Figure A.16: *Fish bone for start-up parts*

A.5 Histograms

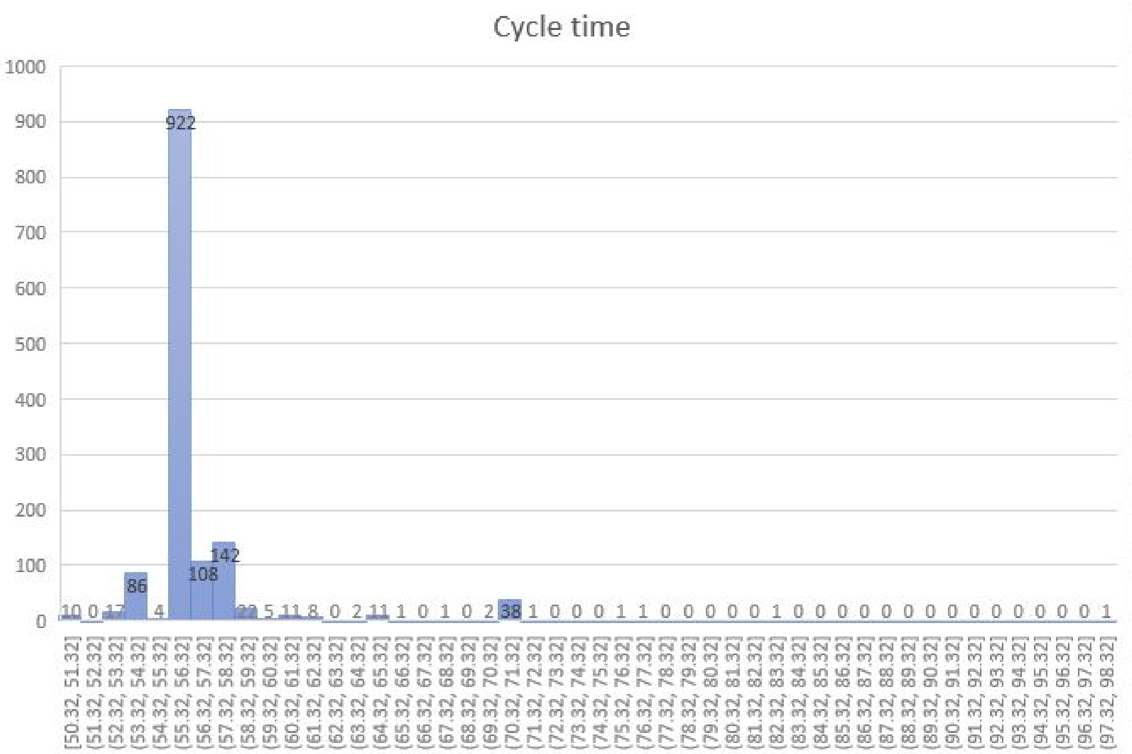

Figure A.17: *Histogram of Product A for cycle time in seconds (ZUs)*

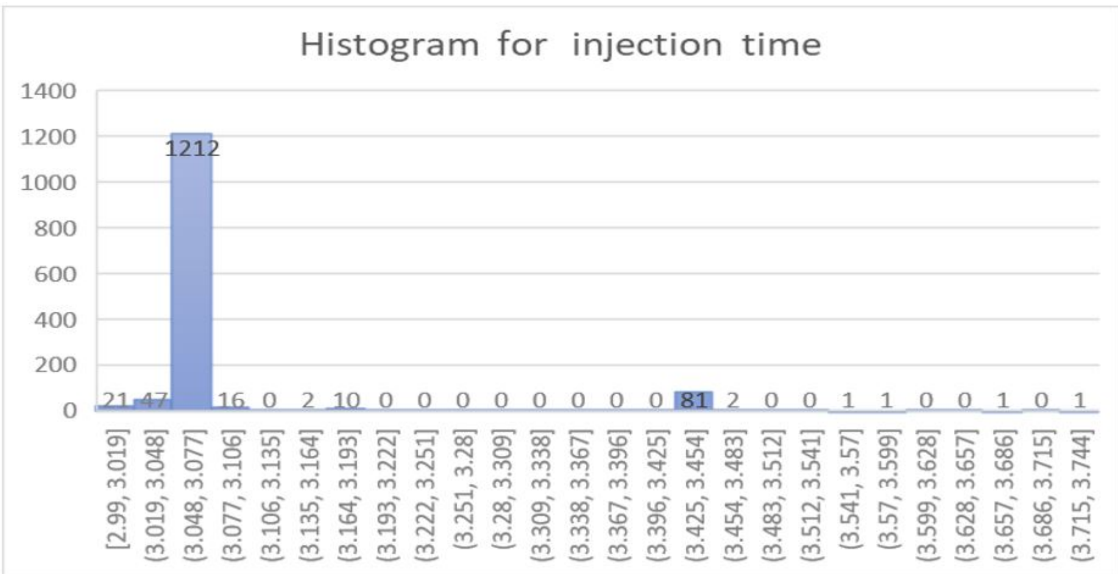

Figure A.18: *Histogram of Product A for injection time in seconds (ZSx)*

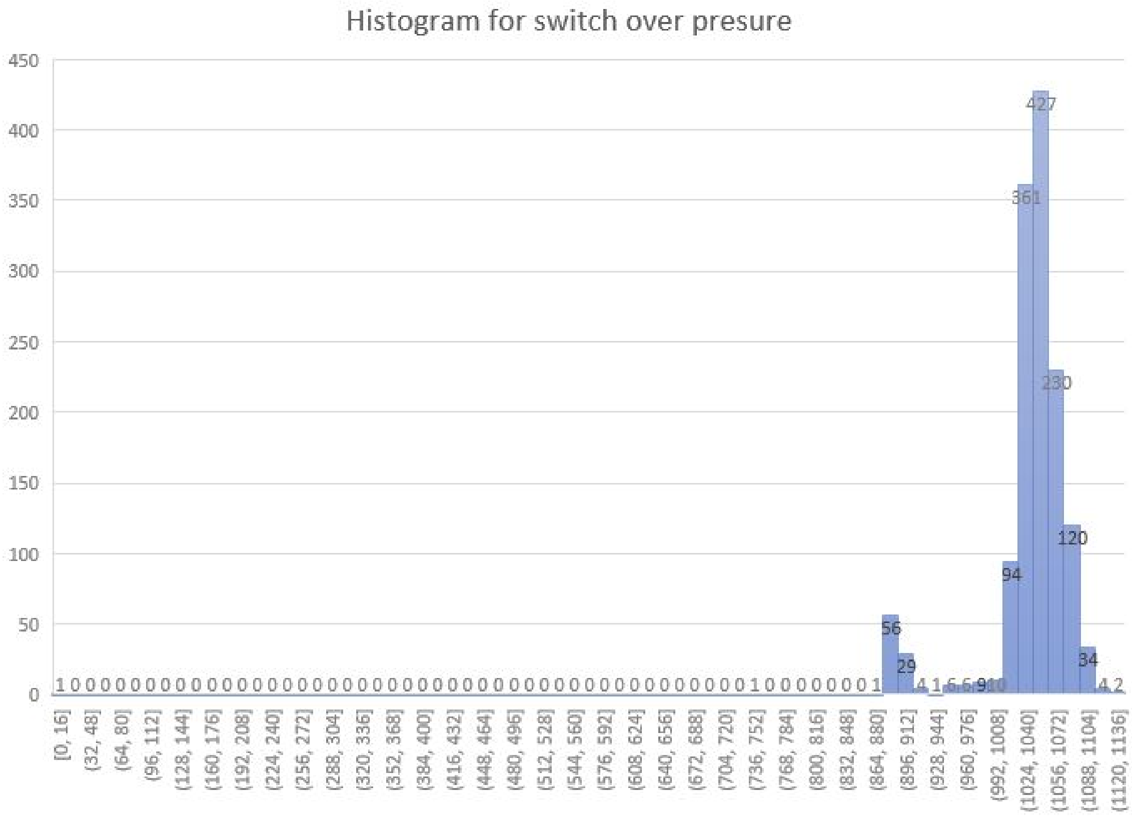

Figure A.19: *Histogram of Product A for switch over pressure in bars (APHu)*

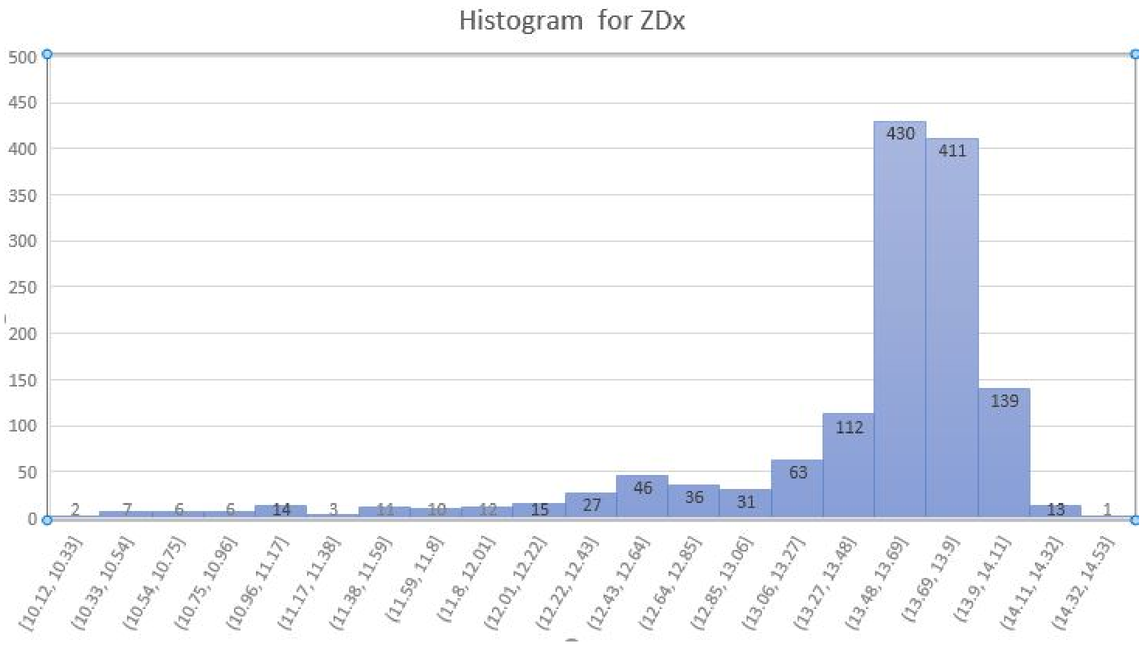

Figure A.20: *Histogram of Product A for Dosing or Metering Time in Seconds (ZDx)*

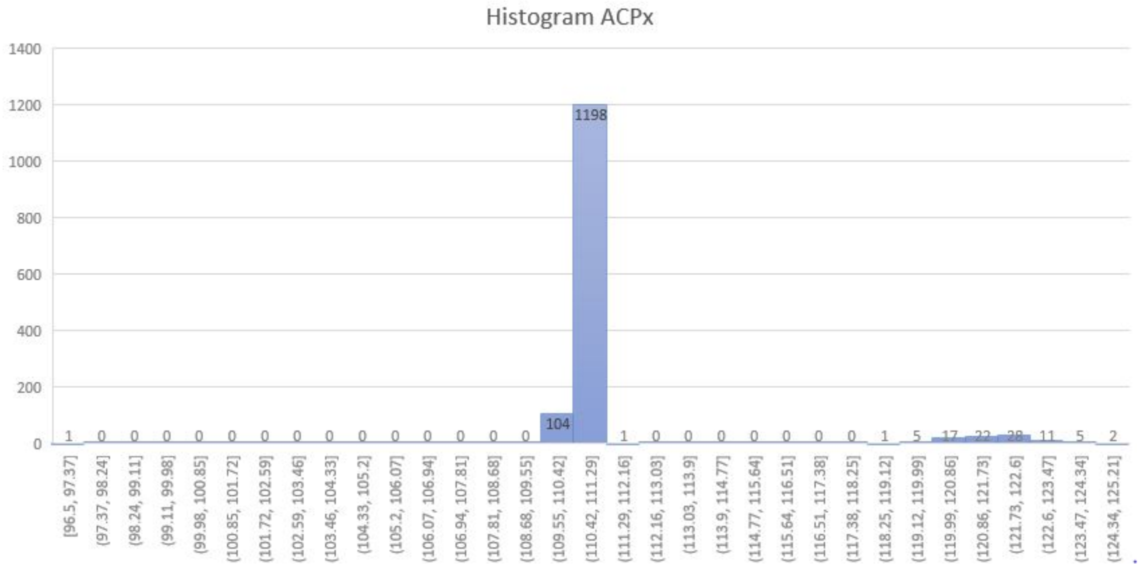

Figure A.21: *Histogram of Product A for Mass Pillow Minimum Value in Cubic Centimeters (ACPx)*