IMPROVING CASTING PROCESS BY REDUCING SMALL PART DEFECT USING SIX SIGMA DMAIC APPROACH AT PT. LOL

By

Mochamad Didit Prakoso

004201300032

A Thesis Submitted to the Faculty of Engineering President University in Partial Fulfillment of the Requirements of Bachelor Degree in Engineering Major in Industrial Engineering

2017

THESIS ADVISOR
RECOMMENDATION LETTER

This thesis entitled **"Improving Casting Process by Reducing Small Part Defect Using Six Sigma Approach at PT. LOL"** is prepared and submitted by **Mochamad Didit Prakoso** in partial fulfillment of the requirements for the degree of Bachelor Degree in the Faculty of Engineering has been reviewed and found to have satisfied the requirements for a thesis fit to be examined. I therefore recommend this thesis for Oral Defense.

Cikarang, January 27th 2017

Johan Krisnanto Runtuk, M.T.

DECLARATION OF ORIGINALITY

I declare that this thesis entitled **"Improving Casting Process by Reducing Small Part Defect Using Six Sigma Approach at PT. LOL"** is, to the best of my knowledge and belief, an original piece of work that has not been submitted, either in whole or in part, to another university to obtain a degree.

Cikarang, January 27th 2016

Mochamad Didit Prakoso

"IMPROVING CASTING PROCESS BY REDUCING SMALL PART DEFECT USING SIX SIGMA APPROACH AT PT. LOL"

By

Mochamad Didit Prakoso

ID No. 004201300032

Approved by

Johan Krisnanto Runtuk, M.T.	Prof. Dr. Ir. H. M. Yani Syafei, MT
Thesis Advisor I	Thesis Advisor II

Ir. Andira, M.T

Program Head of Industrial Engineering

ABSTRACT

The competition among company has become strict nowadays, PT. LOL as the vendor of battery manufacturing had a commitment with the quality of the product. Recently, PT LOL get a complaint by the customer. The customer complaint about the quality of small part MH that PT. LOL manufactures. Quality Control Division of PT. LOL conduct observation about casting process that leads to the high number of defect. In order to reduce the number of defect, especially in small part MH, the casting process has to be improved by using Six Sigma with DMAIC approach. After conduct the observation in casting process, it is known that most of defect is categorized as shrinkage with the percentage of 12% out of 1,072,172 units of small part MH produce on period June-September 2016 by using Pareto Chart. The root causes of shrinkage have to be analyze, and one of the root cause was parameter setting in casting process. To reduce the number of shrinkage defect, design of experiment was done. The purpose of design of experiment is to find the best new parameters, these parameters aims to reduce the number of shrinkage in small part MH. The result of design of experiment is 450^{o}C of melted lead and 8 seconds of cooling time. Then the investigation using new parameters was conducted. The result is using new parameters shrinkage has reduce from 12% to 4% accompanied with another type of defects. The total defect percentage of small part MH has reduce to 10% from 19%. With the data from investigation it is expected that new parameters can reduce the loss 55% from before.

Keywords : *Defect, Casting process, Six Sigma, DMAIC approach, Quality Control Division, Pareto chart, Cause and effect diagram, Design of experiment, Two-way ANOVA.*

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to Allah SWT who always listens and helps me whenever I pray. This report will not be successful without a big support and great encouragement from everyone around me, Therefore, I would like to express my gratitude to:

1. My family, my mother, my father, and my sisters, they are the source of my love, the one who gives me support to conquer all obstacles.
2. My beloved thesis advisors, Sir Johan and Prof. Yani thank you for guiding me to finish this final assignment.
3. My super friends duo Capricorn who always support me and give me some useless qoutes, Aldino Fajri and Purnama Sahid Antasara.
4. My beloved friends, Raydi Radifan, Mas Bagoes, Fariz, and Atho.
5. My strong girls, Nabila, Nia, Marsha, Nadila, Tari, and Putri, who always support me and giving me the foods.
6. My beloved friends IE 2013, who passing this tough 3.5 years in President University, and always accompany me. Best wishes for you guys.
7. Aldino, Raydi, and Atho's boarding room, thank you for your kindness to let me use your wifi, soap, shampoo, and even electricity.
8. My highschool friends, Acong, Agus, Egi, Racun, Faiz and Ajie, thank you for all wonderful moments we have shared.
9. My big family, engineering President University, thank you all for this 3.5 years

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF TERMINOLOGIES

Casting	: Casting is a process, in which liquid metal is poured into a mold
Defect	: Complete product that different with the design or specification of the product.
DMAIC	: An Improvement method that contains of Define, Measure, Analyze, Improve, and Control, which use to improve and optimize the business process in a company.
Quality Control Division	: Division in company, that have to check and make sure the product and process have to follow the standardize by company or organization.
Small Part	: Small part is a part in battery, it aims to put the screws on the battery poles, it made by lead.

CHAPTER I

INTRODUCTION

1.1 Problem Background

Nowadays the competition among company become strict, one of many sectors which every company compete in is quality. Quality of the product must be considered well, because when the quality of the goods is bad it will affect the brand image and of course the competitor can take over the market. Quality is conformance to requirements or specifications (Crosby, 1979). A good quality of product is determined by its production process, good production process will produce good quality of products. While if there is something wrong in the process it will affect the quality in other words there will be some defects in goods.

Defect is the failure of producing the product that is appropriate with customer needs and also goods can be categorized as defect when the design of product is not met the specification. (Santos and Barbosa, 2006) stated that casting defects are usually easy to characterize, but to eradicate them could be a difficult task. Defects are caused by the combined effect of different factors.

Six sigma helps the organization to make the process more effectively so there will be no waste. Most of the organization used six sigma as a method to reducing the defects. Six Sigma is a project-driven approach and by which the organization can achieve the strategic goal through effectively accomplishing projects (Kumar, 2013). It also organized strategic process improvement that relies on several statistical method and also scientific method to make reduction of defect rates. Define-Measure-

Analyze-Improve-Control (DMAIC) framework of Six Sigma methodology has been well established as a tool for process improvement and customer satisfaction.

Serveral researches about six sigma DMAIC has been used for reducing the defects in the manufacturing process and it is effective as well. All the researcher using many tools that can be combined with six sigma DMAIC. One of the examples is the application of six sigma DMAIC for reduction of defects in rubber gloves. In this research the researcher use experimental design as a tool that will be combined with six sigma to achieve the minimum defects rate.

PT. LOL as a vendor for battery manufacturing is produced small part for motorcycle battery and cas battery. This small part is the important part of battery, it aims to put the screws on the battery poles. Because battery has strict safety standards from Indonesian government, quality for each part in battery has to fulfilled the safety standard, in other words quality the small part produced by PT. LOL should be good enough to fulfill the requirement. Since that PT. LOL has committed to produce good quality of small part. In order to make small part for battery, all the process performance have to be controlled. The purpose of performance control is to prevent the non-conformity or defective result on small part. A successful control is reflected from its variation as well as having an in control process.

Recently, PT. LOL realizes it has high percentage of defects, which results in customer complaints and also increasing the production cost due to cover the rework. Customer complaints that PT. LOL has deliver shrinkage product which cannot be used as small part for battery. Because of this situation, the profit of PT. LOL is decreasing. To minimize that situation occur in the future, quality control in PT. LOL conduct the observation in order to find the process which produce high percentage of defects. this lead to loss for the company for about IDR 25,962,568 for rework this happened during April 2016 – July 2016. After conducting the observation, most of defects come small part MH from casting process, the percentage of defect is about 19%.

In order to reduce the defect on small part and increasing the productivity and also reduce the loss caused by defect, casting process has to be improved using six sigma DMAIC methodology with two-way anova as a tool since there are two factor that affected the quality of goods in mold casting process.

1.2 Problem Statement

Based on the problem background above, these are the statements related to the problem:

- How to reduce defects in casting process by using Six Sigma DMAIC methodology in PT. LOL?

1.3 Objectives

The main objective of this research are as follow:

- To reduce defects in casting process by using Six Sigma DMAIC methodology in PT. LOL.

1.4 Scopes

Due to the limited time and resources in finishing this research, there are some scopes for this research:

- The research was conducted on July 2016 to October 2016 in casting process of small part.
- The observation focused on MH part for car battery.

1.5 Assumptions

These are the assumptions for this research in order to run the analysis properly

- The significance level is assumed 5%
- The operator of casting have the same level of skill.

1.6 Research outline

Chapter I — **Introduction**

This chapter explains about the background of problem occurred, problem statement, research objectives, scopes, assumptions and the description of research outline.

Chapter II — **Literature Study**

This chapter delivers study about six sigma as the main method and other quality tools/theory which support this research.

Chapter III — **Research Methodology**

This chapter describes the flow of the whole process of the research.

Chapter IV — **Data Collection and Analysis**

The data observation is processed & analyzed in this chapter. The result of data analysis is the improvement process on small part MH, which expected to decrease the defect number.

Chapter V — **Conclusion and Recommendation**

This chapter gives the conclusion of the research along with the recommendation for the future research.

The introduction as the first chapter to give direction and guidance of this research in achieving the objectives mentioned. After explain this chapter clearly, the next chapter which is literature studies will be presented in the next chapter.

CHAPTER II

LITERATURE STUDY

2.1 Casting

Casting is a process, in which liquid metal is poured into a mold that contains a hollow cavity of the desired shape, and then allowed to cool and solidify (De Garmo, 2003). As complicated production process, casting carries risk of failures occurrence during all the process of accomplishment of the finished products (Kumar, 2013). The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting is most often used for making complex shapes that would be difficult or uneconomical to make by other methods. There are some aspects that have to be controlled in casting process which are:

- Cooling curves

  Cooling curves or in other word is cooling rate is a line graph that represents the change of phase of matter, typically from a gas to a solid or a liquid to a solid. The independent variable (X-axis) is time and the dependent variable (Y-axis) is temperature (Garland, 2003). Below is an example of a cooling curve used in casting. The example of cooling curves is shown in figure 2.1.

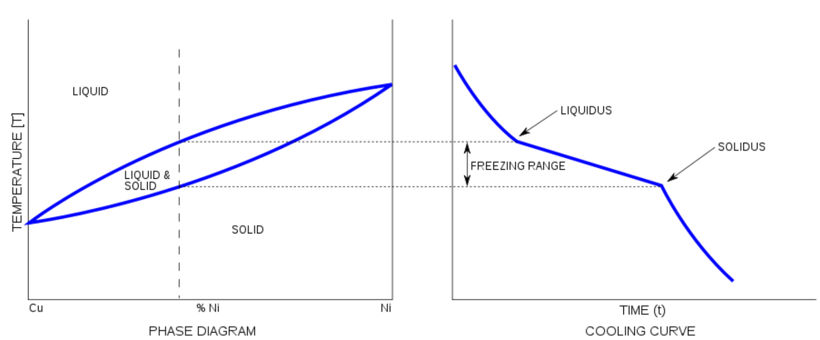


Figure 2.1 Cooling Curves

- Mold cavity

  The mold cavity of a casting does not reflect the exact dimensions of the finished part due to a number of reasons. These modifications to the mold cavity are known as allowances and account for patternmaker's shrinkage, draft, machining, and distortion. In non-expendable processes, these allowances are imparted directly into the permanent mold, but in expendable mold processes, it is imparted into the patterns, which later form the mold cavity.

  For surfaces of the casting that are perpendicular to the parting line of the mold a draft must be included. This is so that the casting can be released in non-expendable processes or the pattern can be released from the mold without destroying the mold in expendable processes. The required draft angle depends on the size and shape of the feature, the depth of the mold cavity, how the part or pattern is being removed from the mold, the pattern or part material, the mold material, and the process type. .

2.2 Defect

Product defect is the failure of producing the product that is appropriate with customer needs. A product also can be categorized as defect when the quality of product is not meet certain standards (Mitra, 2008), it means that the complete product is different with the design or specification of the product. The effect of different factors will caused defect (Greenhill and Palmer, 1973). Other than that, when the design is correct but the manufacturing process is incorrect and produce different product, the product also called as defect product. A product also considered as defect when the product cannot function as the real function of the product. The company won't sell the malfunction or defective product, because the malfunction of the product is can be dangerous for customer that uses it.

There are several disadvantages of defect product that will disadvantage to the company. For example, if the specification of bottom case from casting process is not meeting the requirement, the potential impact will occur after the shock absorber is assembled, causing bottom case cannot stand the force of shock when the motorcycle hit the hole and will wreck the shock absorber. Defect can be defined as the bad result in the production system that produces a product. Defect also can cause the product become less valuable and less effective. Defect is bad for every company because when there defect occur the company might get several disadvantages. The disadvantages can be in the form of money, because when the product is defect that product cannot be selling to the customer and become a waste.

2.2.1 Types of defects in Casting

In casting process there are some defects that can be categorized as:

- Blowhole or Unfilled

  Blowhole or unfilled can be categorized as cavities defect, which is also divided into pinhole and subsurface blowhole. Pinhole is very tiny hole. Subsurface blowhole only can be seen after machining. Blowhole occurred when the gases entrapped by solidifying metal on the surface of the casting. Frequently associated with slags or oxides. The defects are nearly always located in the cope part of the mold in poorly vented pockets and undercuts.

- Flash

  Flash is a molding defect that occurs when some molten materials escapes from the mold cavity. Typical routes for escape are through the parting line or ejector pin locations. This extrusion cools and remains attached to the finished product. The example of flash defect can be seen in figure 2.2.

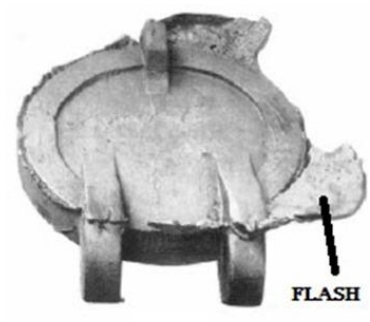


Figure 2.2 Flash

- Cracks or tears Cracks

  It can be appeared in die castings from a number of causes. Some cracks are very obvious and can easily be seen with the naked eye. Other cracks are very difficult to see without magnification. The example of crack can be seen in figure 2.3.

Figure 2.3 Crack

- Shrinkage

  Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies. There are two sorts of shrinkage, which are open shrinkage and close shrinkage. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates. Closed shrinkage defects, also known as shrinkage porosity, are defects that form within the casting. Isolated pools of liquid form inside solidified metal, which are called hot spots. The dissolved gas can induce closed shrinkage defects. The defects are broken up into macro-porosity and micro-porosity (or micro-shrinkage), where macro-porosity can be seen by the naked eye and micro-porosity cannot. The example of shrinkage defect can be seen in figure 2.4.

Figure 2.4 Shrinkage

2.3 Six Sigma

The Six Sigma Methodology is continuous improvement strategy that minimizes defects and variation towards an achievement of 3.4 defects per million opportunities (Gutierrez *et al*., 2004). It was developed at Motorola by an engineer Bill Smith in the mid 1980s. Six sigma has other meaning as one of the method to control the quality of the product, this is one of the most common method that people use to improve their quality management. Six sigma is one of quality management that focused on reducing mistakes in process.

Many foundries are interested to implement Six Sigma to improve the quality of their products (Arita and McCann, 2002). Indeed, the implementation of Six Sigma methodology into foundry has become globally popular. The selection of right projects in a Six Sigma program is a major concern for early success and long-term acceptance within any organization (Ray and Das, 2010). There are several concepts about the principle of six sigma. Six sigma has a key point to determining the customer requirement and then defining defects.

Six sigma is well known method that most of manufacturing with several tools that can be used for reducing the defects. The lower value of six sigma means that less error in production process, because there is an inverse between the sigma level and number of errors. In order to determine the appropriate level, it will depend on the importance strategic of the process and improvement cost that are relative with the benefits. There is no need to operate all the processes in the Six Sigma level. If the process is at two or three sigma level, it will be relatively easy and have an effective cost to reach the four sigma level. Then, to reach five and six sigma level, it requires more effort and more statistical tools. From the previous explanation, it means that the higher sigma level the more difficult it would be. There will be more calculation with using the statistical tools. The effort and difficulty will be increase as the process six sigma is increase .

There are some requirements in conducting six sigma that the process have to met, first one is the process is in controlled. If the variations that occur in the process is low, it will be easy to anticipate any result (output) of the process. If a process is controlled, it can be improved. Next is a process that is well documented, without documentation (handwritten or electronic), the process is only going to be a kind of knowledge and a set of jobs traditionally performed in sequence. Traditional knowledge is very vulnerable to changes, because the description relies heavily on oral transmission, so understanding the process could be chaotic and perverse. With documentation, the description and the original description of the process will be maintained.

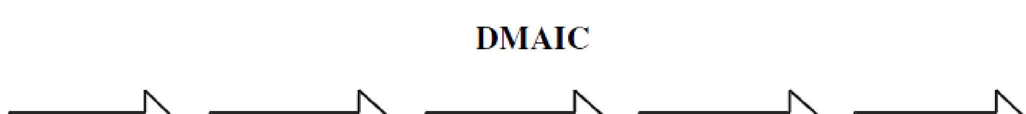
Six sigma methodologies has successfully implemented with more than two decades at major corporations (Kumar *et al*., 2008). Six sigma can be used to reduce defect rates and failures in the manufacturing processes. In other words, six sigma can reduce the production cost due to rework for defect products. Another advantages of six sigma is improved the quality, by conducting six sigma, the organization can defined the problem in the process and execute the problem into some actions that can improved the quality. Six Sigma have benefited in three major ways: reduced defect rate; reduced operational costs; and increased value for both customers and shareholders (Antony, 2008). The other objectives of six sigma is reduce defect that happen until it have zero defect level. There are also ratio of defect that shows the standard level of defect percentage. As have been stated before, the most common six sigma level have a percentage of 99.9997% it means the ratio of defect is 3.4 defects of million opportunity (DPMO).

Table 2.1 Sigma level

Sigma Level	DPMO	Process Yield
1	500000	50%
2	308537	65%
3	66807	93%
4	6210	99.4%
5	233	99.976%
6	3.4	99.9997%

2.4 DMAIC Phase

Six sigma focused on several aspects, which are customer identification, product identification, process identification, prevent mistakes that happen in production process and reduce too much waste. (DMAIC) framework of Six Sigma methodology has been well established as a tool for process improvement. The DMAIC model refers to five interconnected stages that systematically help organizations to solve problems and improve the processes (Ploytip, 2013). The DMAIC model indicates,



step by step, how problems should be addressed, grouping quality tools, while establishing a standardized routine to solve problems (Bezerra et al., 2010).

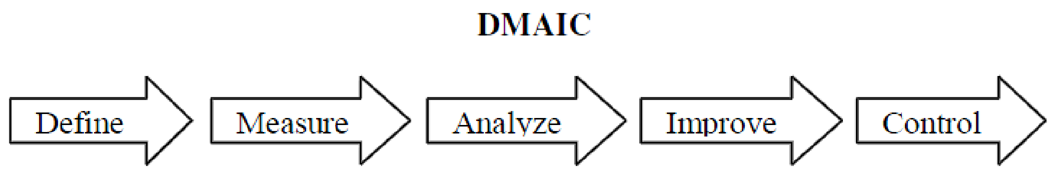


Figure 2.5 DMAIC Phase

2.4.1 Define Phase

Define phase will define the scope and goals of the improvement project to fulfill the customer requirements. Define phase is the phase to determine or define the objective, activities and scope for using this method. The main objectives of this phase are focus to the target straight to the point to improve the quality management. There are several targets that people can choose in this phase, which are output production, productivity, decreasing defect product, and operational cost. Then, the target will affect several aspects in the production system, including operational level, decrease the machine downtime, and other aspects.

2.4.1.1 Project Charter

In order to ensure that the research is in-control and focuses on the project problem explicitly, the boundary of the project had to also be defined and clearly indicated (Ploytip, 2013). To assured the commitment towards the project, conduct project charter. Project charter is a tool used to document the objectives of the project and other parameters at the outset (Pande *et al.*, 2000). Project charter summarize all of the aspects that needed for the research such as project's boundary or scope, objective of the research, and Voice of Customer. The example of project charter is shown in figure 2.6.

Project title	Defects reduction in rubber gloves
Background and reasons for selecting the project	A large amount of rubber gloves has been rejected by customers due to they were defective. This problem causes several types of losses to the company, for example, time, materials, capital as well as it creates customers' dissatisfaction, which negatively affects the organisation's image
Project objective	To reduce the defects by 50 per cent after applying Six Sigma into the gloves manufacturing process
Voice of the customer (VOC)	Product's quality
Project boundary	Focusing the gloves solely on "medium" (M) size
Team members	Production manager, an experience shop-floor operator and the improvement project leader
Expected financial benefits	A considerable cost saving due to defects reduction
Expected customer benefits	Receiving the product with the expected quality

Figure 2.6 Project Charter
Source: Jirasukprasert Ploytip, 2013, 10 p

2.4.1.2 Flowchart

Flowchart is a basic graphical tool used for displaying processes' flow sequentially (Pyzdek and Keller, 2010). Once that the inputs, outputs and sequence of the process were understood with the help of the flowchart, an analysis was carried out to identify the root causes of the quality defect (Ploytip, 2013). In a simple flowchart contains some symbols, each symbol represent process, decision, and flow. Flowchart was introduced by Frank and Lillian Gilbreth in 1921. The example of flowchart can be seen in figure 2.7.

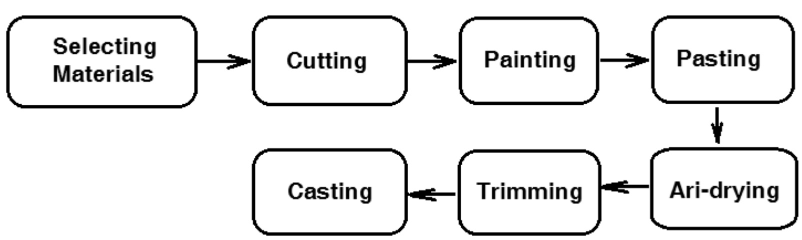


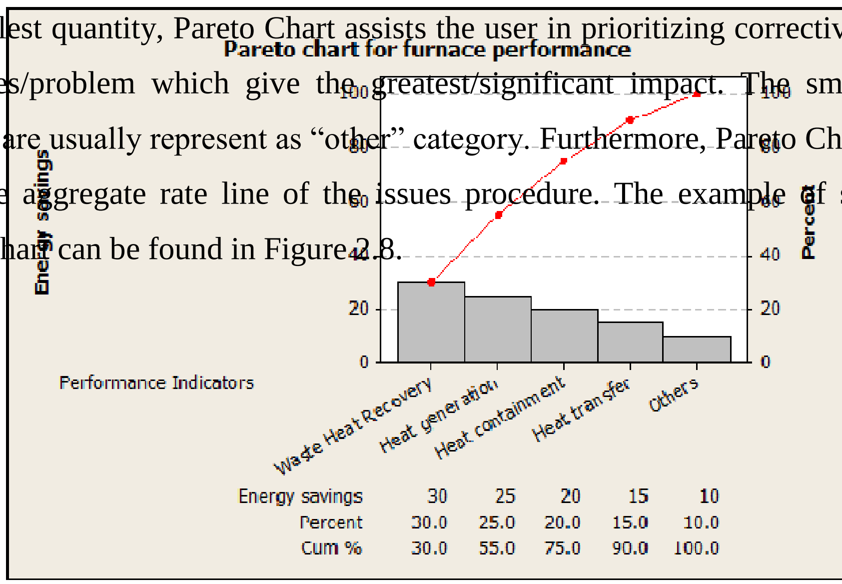
Figure 2.7 Flowchart

2.4.2 Measure Phase

The next phase is measure phase that will continue the phase from the define phase. Measure phase is the second phase in improving the quality management. This phase has an objective to collect the necessary data that will be used to validate the problem. The other objective is to understand and establish the performance of process. Other than that, this phase will show several facts that will give the hint for determining the root cause.

2.4.2.1 Pareto Chart

The history of Pareto Chart is named after Pareto’s law which state the number of causes that produce the largest impact. Pareto chart is a specific type of bar chart that represent categories. Pareto chart ranks or issues by the overall influence. The issues are often represent as defect and trouble. As Pareto are arranged from the largest to the smallest quantity, Pareto Chart assists the user in prioritizing corrective action on the issues/problem which give the greatest/significant impact. The smallest issue quantity are usually represent as “other” category. Furthermore, Pareto Chart likewise show the aggregate rate line of the issues procedure. The example of structure of Pareto Chart can be found in Figure 2.8.



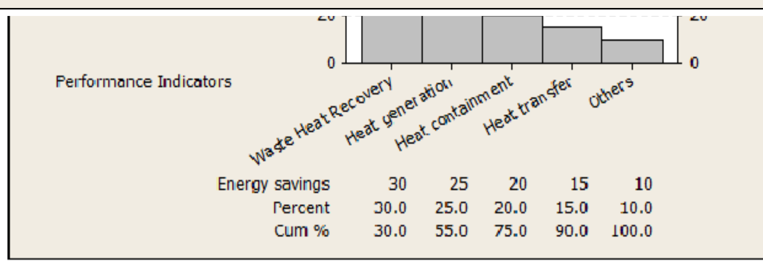


Figure 2.8 Example of Pareto Chart Structure

2.4.2.2 Defect Per Million Opportunities (DPMO)

DPMO is a unit of measurement for the quality of the product process. The equation below is to calculate DPMO.

$$Defective\ Percentage = \frac{Total\ Defect}{Total\ Sample} * 100\% \qquad (2\text{-}1)$$

$$DPMO = \frac{1.000.000 * Total\ Defect}{Total\ Sample * Defect\ Opportunities} \qquad (2\text{-}2)$$

2.4.2.3 Sigma Level

After calculating DPMO next step is calculate the sigma level. Sigma level will help to measure the sigma level of current condition. Figure 2.9 shown the detail about calculation of sigma level using microsoft excel.

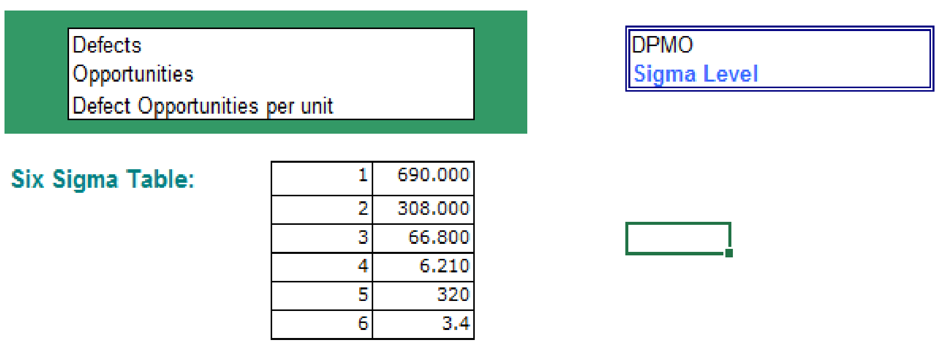


Figure 2.9 Six Sigma Calculator

The formula of sigma level in excel

-norm.s.inv(DPMO/1,000,000)+1.5

2.4.3 Analyze Phase

Analyze phase will determine the root cause of the problem. Other than that, the analyze phase will analysis the potential causes of defects. The data that already collected from measure phase will be analyze and calculated until the main effect of the problem can be obtain. There are several important aspects that affect in this phase, those are process capability and identified source of variation. This phase will help to determine the step that is need to improve in the process.

There are several aspects that are related to determine the variable in this phase. Those are man power, machines, methods, materials, media, motivation, and money. Man power will be related with the employee performance inside the company. Machine is related with all the facilities, tools, production machine that is used in the company. Material as the basic material to produce the product of the company

Media shows every condition that affects the operator, which are the cleanliness, health, operator safety, and environment condition. Motivation comes from the attitude of the operator in doing their job, which can be in the form of appreciation to the operator that already done well in the company. Money as the main factors that can affect many aspects includes company development, quality improvement, employee satisfaction, and etc.

2.4.3.1 Cause and Effect Diagram

Cause and effect diagram can be in the form of fishbone diagram. Cause and effect diagram usually used in analyze phase to help in analyzing the root cause of the problem. Every problem has many factors that can be the cause or the effect.

The cause is the reason why the problem can occur, while the effect is the result of the problem that already occurs. This cause and effect diagram will show clearly the difference between cause of the problem and effect of the problem that occur. The major causes are usually grouped into six specific categories which are mostly used by many manufacturing companies. The categories are below and the example of cause and effect diagram can be seen in figure 2.10:

1. Personnel: Manpower involved in the process.

2. Machines: Mechanical tools that support the process.

3. Materials: Basic input to produce final output during process.

4. Methods: The way how the process is performed based on requirements standards / procedures / rules.

5. Management: The way the data are collected from the process as the evaluation of its quality.

6. Environment: The conditions nearby that influence or affect the process such as time, temperature, location, culture, and etc.

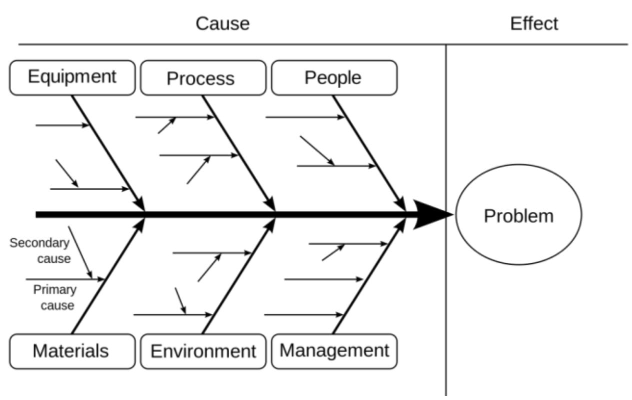


Figure 2.10 Example of Cause and Effect Diagram

2.4.4 Improve Phase

Improve phase will help to determine the solution for the problem. The solution that suitable for the problem and can be implemented in the real process. This phase will be focus on the main process in the production process. The solution must fulfill the main objectives, which is improving the quality management. There are two main steps in this phase, which are find the cause of the process variation and determine the relationship of variable that cause the process variation.

In this phase, the new process will be implemented to improve the quality management. The process will be different from before. The operator in the company needs to keep their work performance. The company must not exceed the ratio of defect that already stated. The ratio of defects will be the measurement unit.

2.4.5 Control Phase

Control phase is the last phase in six sigma phase. Control phase will control the performance of new process that already have been improved by the previous phase. In this phase, there will be evaluation for the implemented solution by keep the performance for the future then the problem will not occur again. The improvement must fulfill the main objective of using DMAIC method, which is improving the quality management.

Other than that, control phase will evaluated whether there will be an opportunity that other problem will occur. Control phase also will monitor the result that already implemented and find if there is need a change in the production process to balance the new process.

2.5 Control Chart

In conducting Six sigma with DMAIC approach, the process have to be in-controlled. To see the process is in-controlled, control chart have to be made. Control chart is a statistical tool used to monitor a process over time (Antony, 2011). The theory of control chart is proposed by Walter A. Shewhart in 1920. Control chart contains quality characteristic plotted along vertical axis, while the sample is in horizontal axis (in period of time). Control chart distinguish special causes and common causes from the variation in process. Figure 2.11 shows the example of control chart.

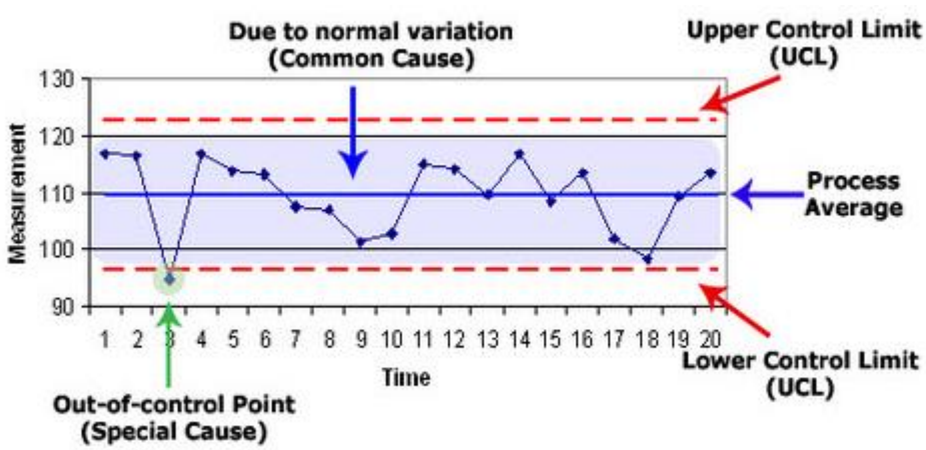


Figure 2.11 The example of Control Chart

There are two limits in control chart, known as Upper Control Limit (UCL) and Lower Control Limit (LCL). Those limits are the trigger that signal when the process is out of control. The centerline of control chart represent the average value of characteristic being plotted. If the value is plotted out of control limit, it can be seen that there is special cause in the process that must be taken remedial action to bring the process back into control. There are several control chart that can be made to monitor the process such as: P- Chart, C-chart, and U-chart for data attribute. P-chart is useful for measuring the defective proportion in production. C-chart is for measuring the number of defect in unit production. Not different with C-chart, U-chart also measuring the number of defect in unit but the sample that taken for U-chart is not constant. Due to this research that mention about defect, so the proper control chart that used for the process is U-chart (Antony, 2011). Centerline, UCL, and LCL of U- Chart can be calculated as:

$$\text{CL} : \bar{U} = \frac{\Sigma c}{\Sigma n} \quad (2\text{-}3)$$

$$U_i = \frac{Ci}{ni} \quad (2\text{-}4)$$

$$\text{UCL} = \bar{U} + 3\sqrt{\frac{\bar{U}}{ni}} \quad (2\text{-}5)$$

$$\text{LCL} = \bar{U} - 3\sqrt{\frac{\bar{U}}{ni}} \quad (2\text{-}6)$$

Where:

c is number of defect

n is number of sample

n_i is number of sample for every observation

2.5.1 Analyze of patterns in control chart

Control char is used to determine when the process is out of control, so it can take necessary actions to improve it. The process is out of control or not can be seen from some indications that control chart shows (Mitra, 2008). There are several rules that can be used to identify an out-of-control process. These are 5 rules which the most occur in the process:

1. Rule 1 (one or more point plot outside the control limits)

   This first rule is commonly used. When the control limits are placed in three standard deviation from the mean and there is one point or more plotted outside control limits, it is indicate that the process is out of control. If the standard deviation is three the probability of a point plotted outside the limits is very small (Mitra, 2008). The example of rule 1 can be seen in figure 2.12.

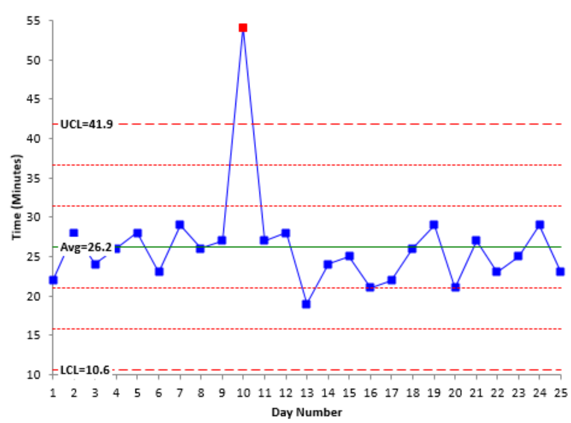


Figure 2.12 The example of rule 1

2. Rule 2 (two out of three consecutive points fall outside 2σ from mean on the same side)

2σ is a warning limits from the centerline. The process can be stated as in control, if there is less then two points plotted in 2σ are on the same side. The chance of points plotted in 2σ will small if the process is in control. Example of rule 2 can be seen in figure 2.13.

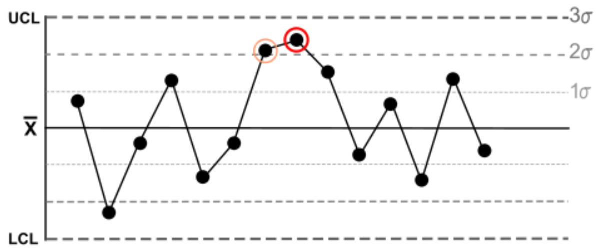


Figure 2.13 The example of rule 2

3. Rule 3 (four out of five consecutive points fall beyond the 1σ limits from mean on the same side)

   If there are four out of five consecutive points plotted on the same side beyond 1σ, it can be seen as an indicator that the process is out of control. The distance between centerline or mean with upper or lower limit control is 3σ (Mitra, 2008). By that explaination, the distance is divided into 3 limits, 1σ limits, 2σ limits, and 3σ limits. The example of rule 3 can be seen in figure 2.14.

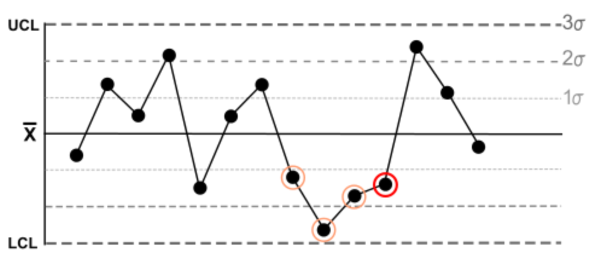
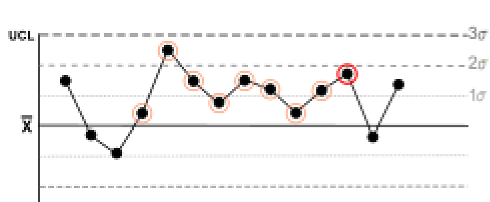


Figure 2.14 The example of rule 3

4. Rule 4 (nine or more consecutive points fall to one side of the centerline)

   The pattern in rule for indicates the tendency of process may go higher than normal condition. It occurs when nine or more censecutive points plotted to



one side of centerline. In order to eliminate the cause, corrective action should be taken. The example of rule 4 can be seen in figure 2.15.

Figure 2.15 The example of rule 4

5. Rule 5 (six or more consecutive points steadily increasing or decreasing)
   Six or more consecutive points increasing or decreasing indicates that there is a trend in process. If the process is in control the chance of trend occurs is small. Necessary action is neede in order to eliminate the trend in process. Figure 2.16 show the example of rule 5.

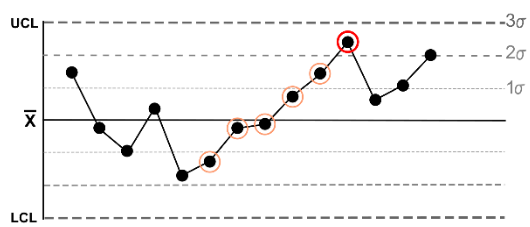


Figure 2.16 The example of rule 5

2.6 Experimental Design

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. It aims to increase the product quality and process efficiency. The purpose of experimental design is to identify the reason of changes from the input variable (factors) resulting to the output response. Conducting experimental design will provide valid result through statistical model on how significant the input variable impacting the output response (Montgomery, 2009). Another expert (Blake, 1994) stated that experimental design is a strategic weapon to battle competitors worldwide by designing robust products, reducing time to market, improving quality and reliability, and reducing life-cycle cost.

2.6.1 Two-Way ANOVA

ANOVA is a statistical model for comparing differences means of more than two populations (Moore *et al*., 2009). Two-way analysis of variance (ANOVA) is an extension of the one-way ANOVA that analyzing the effect of two factors, is required (Moore *et al*., 2009). The two-way ANOVA not only aims at assessing the main effect of each independent variable but also the interaction between them. The two-way ANOVA examines the effects of one or more independent variables called factors on one or more dependent variables. Dependent variables have to be interval- scaled, for independent variables, the nominal scale level is sufficient.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Framework

Research framework shows the step or guideline to conduct the research. The step of this research are initial observation, problem identification, literature study, data collection, data calculation and analysis, and conclusion and recommendation. There will be a short explanation of each step to give a brief vision about this research.

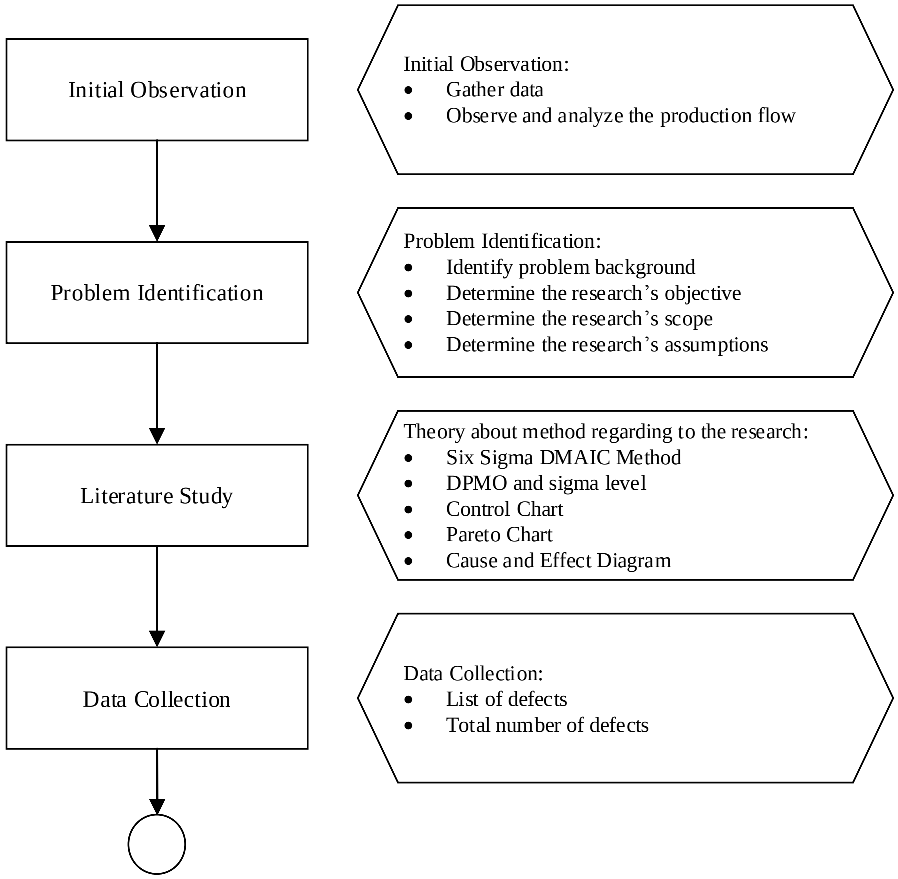


Figure 3.1 Research Framework

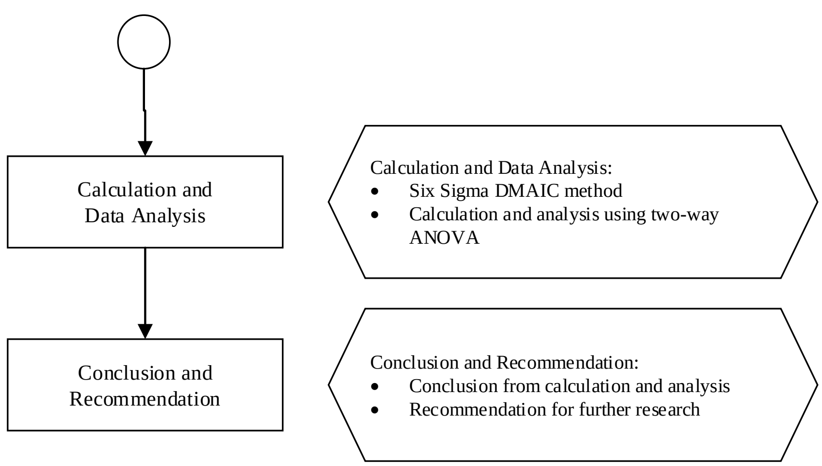


Figure 3.2 Research Framework (Cont'd)

3.1.1 Initial Observation

The initial observation is analyzing the casting process of bottom case for front fork in PT. LOL. The researcher observes every aspect that related to the production system, including material, man, and machine in casting process. From the observation the researcher can gather some important data that can be used for this research.

3.1.2 Problem Identification

After observing casting process in PT. LOL, there is a problem regarding to the output of casting process. PT. LOL produce their product everyday according to the demand that already stated in the company, but there are some products that are defect as the output of casting process. The rate of defects in the casting process are quite high. There are many kind of defects that happen in the casting process, which are shrinkage, pinhole, crack, sand inclusion, and sand burning

There will be problem background that explain about the problem of defect that occur in PT.LOL. Problem statement also can be determine after know about the main problem about reducing fabric defect in the company. The research objective is the answer of the problem statement that already stated, which are reducing the defect in casting process in PT. LOL by using Six Sigma DMAIC method.

3.1.3 Literature Study

There are several theories that related with the problem in this research. The theory can be achieve from several journals and books. The literature study will help to conduct the research. Other than that, it will clearly explain about every method that will be used in this research. It also will give a vision about the researcher must do to face the problem. The background literature consist of Cause-and-Effect Diagram, Pareto Chart, DPMO level, Design of Experiment Two-way ANOVA theorem. More details of all this research's literature study can be seen in the chapter two.

3.1.4 Data Collection

The data that collected will support to conduct the research. The data that are needed for this research are, several kinds of defects that have happen in casting process for bottom case of front fork and the number of defect for each kind of defect. The data also can be collected by the daily report or document about the company.

3.1.5 Calculation and Data Analysis

The method that is used in this research is six sigma DMAIC method. There will be several calculation that will be conducted in this research. One of the calculation is DPMO level. It used to determine the level of defect in the company. Other than that, there is Pareto chart that will determine the highest rate of defect that often happen in the company. The highest rate of defect will become the main problem.

Cause and effect diagram will represent the cause and effect of this color fabric defect problem. The cause as the reason why this problem can occur in this company, while the effect as the future result of this problem that happen in this company. After finding the most appeared defect in casting process. Next is execute the defect using Two-way ANOVA with two factors in casting process which are temperature and speed.

3.1.6 Conclusion and Recommendation

This section contain the summary of all the phase that already done including the main result. The result will be answer the problem of reducing the fabric defect that happen in PT. LOL. In this section also include the advice to the further research.

3.2 Detail Framework

The detail framework for this research are define phase, measure phase, analyze phase, improve phase, and control phase.

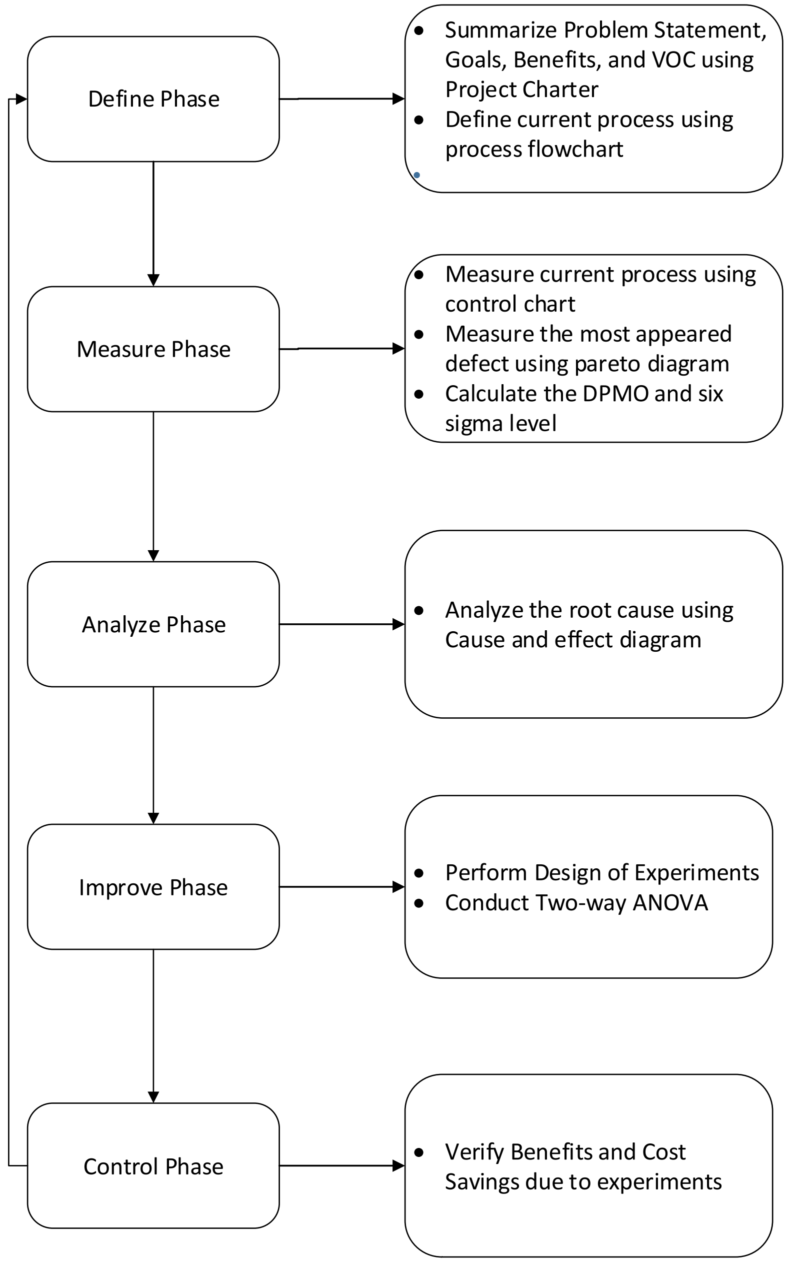


Figure 3.3 Detail Framework

3.2.1 Define Phase

In this phase, the researcher do the observation in casting process and identify the problem. After identify the problem, the researcher defines the objectives, scopes and assumptions for this research. Also define the type of defects in casting process

3.2.2 Measure Phase

In this phase, the researcher made a control chart in order to see whether the casting process is in control or not. Then define most appeared the type of defect in casting process using Pareto Chart. The data is in the form of number to make the calculation become more valid. After that defined the level of DPMO for the most appeared defect

3.2.3 Analysis Phase

In analysis phase, cause-and-effect diagram or fish bone diagram will be used. After know the most appeared defect in casting process, cause-and-effect diagram is needed in order to analyze the root cause of the defect. The cause of defect can be come from many aspects, including the employee performance, uncontrollable speed, and bad quality material

3.2.4 Improve Phase

In order to improve the casting process and reducing the defect the researcher using two-way ANOVA analysis in this research. Improve phase will determine the solution to prevent defect in casting process. The solution that is suitable for the problem and can be implemented in the real production process.

3.2.5 Control Phase

Control phase is the last phase in this method, which have the objective to control the new solution that already implemented in the system by comparing the before and after improvement.

CHAPTER IV

DATA COLLECTION AND ANALYSIS

4.1 Data collection

The data for this research is given from quality control division of PT. LOL. Direct observation has been done in order to obtain the data for analysis, and also brainstorming with expertise from PT. LOL such as: Head of Quality Control division and Production manager were conducted to determine the problems that occurred in casting process and the proper improvement for casting process. Interviewed the expertise is needed to gather the production process of small part MH.

4.2 Product Description

Small part is a part of battery which hold the bolt in the battery. The used of small part is a place for the bold for battery pole. In PT. LOL small part is divided into two categories which are small part for car battery and small part for motorcycle battery. The difference between two small parts is in the weight of the small part. Small part for motorcycle battery is lighter than small part for car battery.

- Small part for motorcycle battery

  The weight of small part for this type is around 35 gr, it is quite light because it considering the motorcycle battery that only have 2.75 kg. To code the small part for motorcycle, the company give code P for every small part that used for motorcycle battery.
- Small part for car battery

  The weight of small part for this type is around 45 gr. This type need more material than small part for motorcycle battery. The company give M code for every small part that used for car battery.

4.3 Production process

To manufacture small part MH, the process consists of several production process such as raw material testing, melting, casting, coating, and packing. From the Quality Control division, casting process has the most defect rate among all of the processes. To simplified the production process flow of small part MH, it shown in figure 4.2.

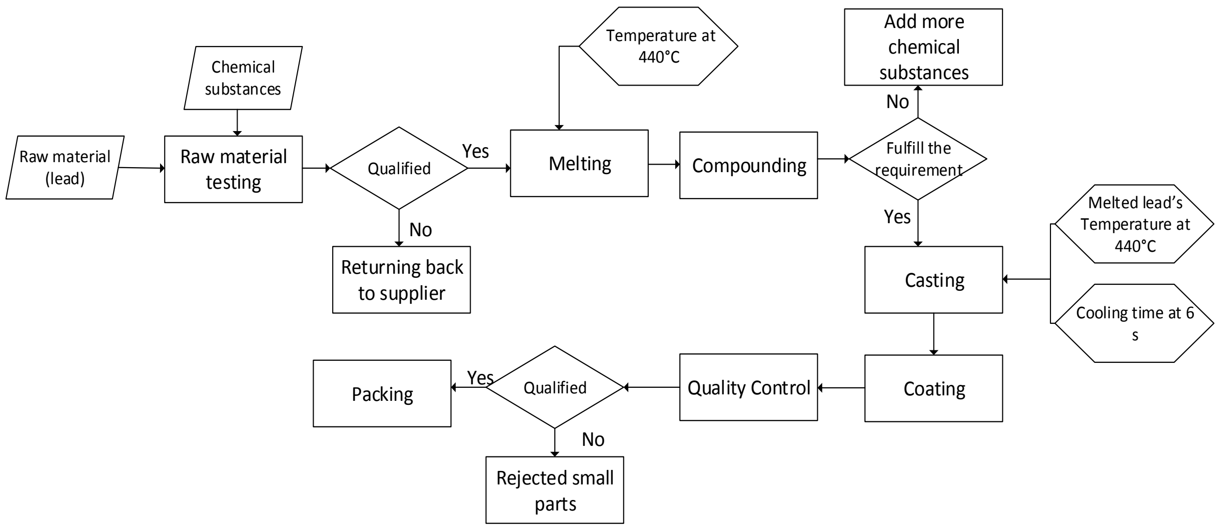


Figure 4.1 Small Part MH Manufacturing Process Flowchart

In the first process, which raw material testing, the material for made small part MH have to be tested first in the lab in order to know the composition of the chemicals in the lead. If the quality of raw material and chemical substances is qualified than the material will go through another process, but if the quality of raw material and chemical substances are bad, it will be returned back to the supplier. After defined the quality of raw materials, then the good quality of raw material move to the next process which is melting process using smelting machine, the temperature of the machine had been set between 440°C. After the raw material melted, then move to the third process which is compounding, this process is combined the raw material with some chemicals in order to fulfill the material requirement for small part MH. The other chemicals are zinc, tin, and etc. If the specification of melted lead fulfill the requirement from the customer, then the melted lead will go to the next process, but in other hands if the specification of the melted lead is not met the requirement then adding some chemical substances is necessary. The forth process is casting process, in this process the melted lead moved to the big crock where the casting machine is located. In this process there are two factors that influence the process which are temperature of melting-pot and cooling time. The parameter of temperature and cooling time both are set in 440^{o}C and 6 seconds. After melted's lead become solid small part MH, then it moved to the next process which is quality control. Quality control need to be conducted after coating the small part to ensure the quality of small part. If the quality of small part is bad then rejected the small part is necessary. There are some category of defects that can be found while done the quality control which are crack, shrinkage, flash, and unfilled. To check the quality, Quality Control division did destructive testing to find the defects in small part. After the quality of small part is already checked next is move to the next process which is coating process. In the coating process the small part that already passed through quality checking dipped in chemical solution named Gum Rosin, this chemical solution helps the small part MH to reduce the possibility to rusty made by a combination of monoterpene, turpentine, and resin acid. The last process of manufacturing small part is packing. The package of small part MH is divided by its type. The package made by plastic, and each plastic consist of 2,500 pcs of small part.

4.4 DMAIC Approach

4.4.1 Define

The first step of Six Sigma and DMAIC approach is define. This step aims at defining the project's scope and boundary and the goal of project. Stating the project's scope was the next step within define phase (Ploytip, 2013). Defining the current production process by conducting observation in the production line. As the main process of manufacture small part, casting process have the biggest impact among the processes in manufacture small part. Regarding to the statement before, the problem is selected for this project is reduce or eliminate quality defects on small part. The objective of this research is reduce the defect. For the organization, listening to customers is critical for a business. To identify the customers want and serving priorities to the customer's needs, Voice of Customer (VOC) concept was used in order to define the customer's requirements. For this research due to customer's complaints about the quality of product, so the Voice of Customer will be product's quality, and all the aspects that have to be concerned in this report will be about product's quality.

As the objective of this research which is reduce the defect by 30% from current condition after conducting six sigma into casting process, the current condition had to be observed first to gather the data about percentage of defect in casting process during June-September 2016 period. The objective was defined by brainstorming with Head of Quality Control Division. The data is divided into two which are data for small part motorcycle battery and car battery. The percentage of defect is shown in table 4.1 and table 4.2.

Table 4.1 Defect percentage in casting process of small part of motorcycle battery in April - July 2016

Type	Number of part produce	Defects	Defect percentage
PTH-7	342,292	42,130	12%
PT-11	294,255	25,766	9%
PT-7 no. 2	55,151	7,380	13%
PT-21 no 2	61,720	8,200	13%
PT-21 no 6	37,265	5,234	14%
PT-21 no 9	389,939	45,267	12%
PT-A13	75,880	9,106	12%
PT-37	300,821	30,382	10%
PT-3S A	58,138	7,721	13%
PT-65	56,693	5,639	10%
PT-10	50,895	4,261	8%

Average	12%

Table 4.1 shows that in small part for motorcycle battery the highest amount of defects occurred in PT-21 no. 6 which had 14%. The lowest amount of defects is in PT-10 which only had 8%. The average percentage of defects in small part for motorcycle is 12%.

Table 4.2 Defect percentage in casting process of small part of car battery in April - July 2016

Type	Number of part produce	Defects	Defect percentage
MH 928 J	676,586	155,318	23%
MH 928 K	297,513	68,591	23%
MH 939-40	72,352	9,947	14%
MH 933-34	10,641	1,531	14%
MH 933-34-B	15,080	3,187	21%
Average			19%

Table 4.2 shows that in small part for car battery the highest amount of defects occurred in both MH 928 J and MH 928 K which had 23%. The lowest amount of defects is in MH 939-40 and MH 933-34 which only had 14%. The average percentage of defects in small part for car battery is 19%. Figure 4.1 shows the current defect rate of casting process in small part for period April – July 2016.

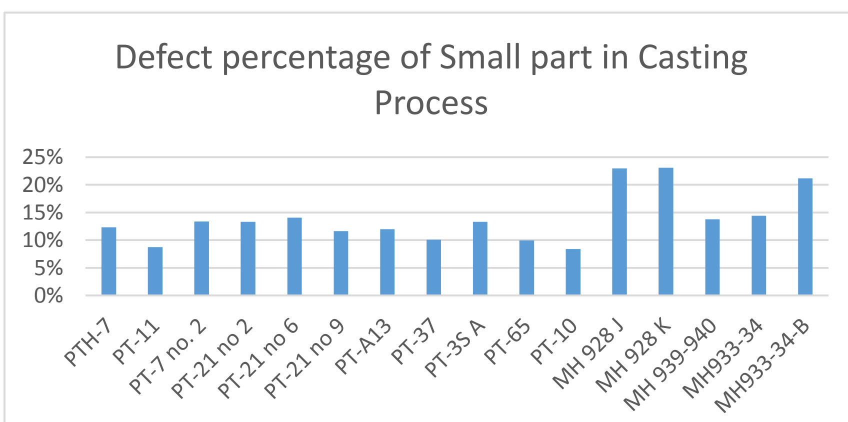


Figure 4.2 Defect rate in casting process of small part in period April – July 2016

Figure 4.2 explain that it can be known that the most defect product is in MH which has 19% of defect and it will be studied in order to meet the minimize the defect rate in casting process. Most defect rate occurred in MH 928 J and MH 928 K for about 23%. Next is the researcher converted the defect rate of product into the cost to know the loss that the company obtained from defects. The detail calculation of cost of gas, electricity, and man power is shown below.

$$Gas\ cost\ per\ Kg = \frac{\text{(Gas price IDR/m3) x Gas consumption (m3)}}{\text{Total production (Kg)}}$$

$$\frac{\text{IDR 4,400/m3 x 4,801 m3}}{\text{24,677 unit}} = \text{IDR 856/Kg}$$

$$Electricity\ cost\ per\ Kg = \frac{\text{Electricity price (IDR/Kwh) x Electricity consumption (Kwh)}}{\text{Total production (Kg)}}$$

$$\frac{\text{IDR 2,277.36/Kwh x 2,655 Kwh}}{\text{24,677 unit}} = \text{IDR 245/Kg}$$

Man power:

IDR 187,000/ Day = IDR 7,792 / Hour

After the cost for gas, electricity and man power is defined, below are the table 4.3 until table 4.6 that show the detail of cost for rework the defect products.

Table 4.3 Rework cost in casting process of small part for motorcycle battery during period April – July 2016

Type	Number of defect	Weight gram/pcs	Total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost
PTH-7	42,130	21	890	217,997	761,656	420,195	1,399,848
PT-11	25,766	27	695	170,318	595,070	154,439	919,828
PT-7 no. 2	7,380	43	319	78,155	273,064	88,469	439,689
PT-21 no 2	8,200	22	183	44,851	156,704	98,299	299,854

PT-21 no 6	5,234	23	122	29,780	104,047	62,739	196,566

Table 4.4 Rework cost in casting process of small part for motorcycle battery during period April – July 2016 (Cont'd)

Type	Number of defect	Weight gram/pcs	Total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost
PT-21 no 9	45,267	23	1,053	258,019	901,485	542,647	1,702,150
PT-A13	9,106	22	197	48,343	168,905	108,116	325,363
PT-37	30,382	17	523	128,105	447,582	344,345	920,032
PT-3S A	7,721	16	126	30,985	108,258	137,513	276,757
PT-65	5,639	22	126	30,892	107,931	70,303	209,125
PT-10	4,261	27	114	27,915	97,532	53,123	178,570
Total	191,086		4,348	1,065,359	3,722,235	2,080,187	6,867,781

Table 4.3 and table 4.4 show the loss that company obtained to rework the defect in small part for motorcycle battery. The cost could be determined by the usage of electricity, gases, and manpower to do the rework. The highest amount of rework cost was in PT-21 no. 9 for about IDR 1,702,150 in period June – September 2016, while the least amount of rework cost was in PT-10 for about IDR 178,570. The total loss during period June-September 2016 was IDR 6,867,781.

Table 4.5 Rework cost in casting process of small part for motorcycle battery during period April – July 2016

Type	Number of defect	Weight gram/pcs	Total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost
MH 928 J	155,318	55	8,524	2,088,344	7,296,417	2,979,047	12,363,808
MH 928 K	68,591	55	3,764	922,247	3,222,219	1,315,596	5,460,062

MH 939-940	9,947	67	670	164,048	573,162	190,787	927,997
MH933-34	1,531	49	74	18,228	63,685	29,365	111,278

Table 4.6 Rework cost in casting process of small part for motorcycle battery during period April – July 2016 (Cont'd)

Type	Number of defect	Weight gram/pcs	Total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost
MH933-34-B	3,187	49	155	37,944	132,571	61,128	231,642
Total	238,574		13,187	3,230,810	11,288,054	4,575,923	19,094,787

Table 4.5 and table 4.6 show the loss that company obtained to rework the defect in small part for car battery during period June - September 2016. The cost could be determined by the usage of electricity, gases, and manpower to do the rework. The highest amount of rework cost was in MH 928 J for about IDR 12,363,808, while the least amount of rework cost was in PT-10 for about IDR 178,570. The total loss during period June-September 2016 was IDR 19,094,787.

After getting the total loss that company obtained by rework the defect product, it can be seen the type of product that had highest amount of loss due to rework. For further phase in DMAIC, the research will be focused on small part MH, because the total most defect occurred in small part MH and also the highest amount of loss that company obtained from defect come from small part MH. The last step of define is gather all the information about the research and summarize all of it, table 4.5 shown the project's scope, boundary, goal or objective and the VOC for this research.

Table 4.7 Project charter

Research title	Defects reduction of small part in casting process
Background and reasons for selecting the	The customer has been rejected a large amount of small part due to defect

research	product. It causes losses to the company such as time, electricity, gas, capital and also negative effects on the organization's image

Table 4.8 Project charter (Cont'd)

Research objective	To reduce the defects by 30% after applying Six Sigma into the casting process
Voice of Customer (VOC)	Product's quality
Research Boundary	Focusing on small part MH
Team member	Head of Quality Control division, production manager, and an experience operator

Table 4.7 and table 4.8 show that the title for this research during conducting six sigma is defects reduction of small part in casting process. The problem background that why this research is selected is because the customer has been complaint and reject a large amount of small part due to defect. Due to the problem background, the objective of this research is reducing the number of defect by 30% in the casting process. The member of project are brainstorming for define the objective. Customer has been rejected small part because of its quality, so the voice of customer as the main demand for this research is product's quality. This research was set to experiment solely with small part MH as the boundary for this research because small part MH has biggest number of defects. As the expert in the organization about small part MH, head of quality control division, production manager, and experience operator have to be in charge in this research.

4.4.2 Measure

After done with the first step which is define, the next step is measure. In the first of measure phase, the current condition of casting process of small part MH have to be measured. In order to measure the current condition, control chart is approriate to conduct. The purpose of control chart is to ensure that the process is in-controlled, if the process is in-controlled, the improvement can be done in this process. Implementing appropriate control chart can do future monitoring of the process for assignable causes (Antony, 2011).The control chart was recorded daily by the quality control division in the last of production in each day. The sampling data of small part MH production can be seen in table 4.9.

Table 4.9 Sampling data for daily control chart of small part MH

Number of observation	Sample	Defect
1	135	25
2	130	30
3	125	20
4	135	35
5	130	25
6	140	30
7	150	35
8	135	25
9	130	30
10	125	25
11	130	30
12	125	25
13	140	35
14	135	30
15	130	30
16	140	25
Total	2135	455

Table 4.9 explains that, the sample taken for control chart is not constant. Quality Control Division take a sample for every 1.5 hour production hour, this aims to make sure that the process always in the control of Quality Control Division. It is estimated that the total defects in every type of small part per production day out of 427 sample taken. Each day there will be 16 observation on small part MH. Control chart can be seen in figure 4.3.

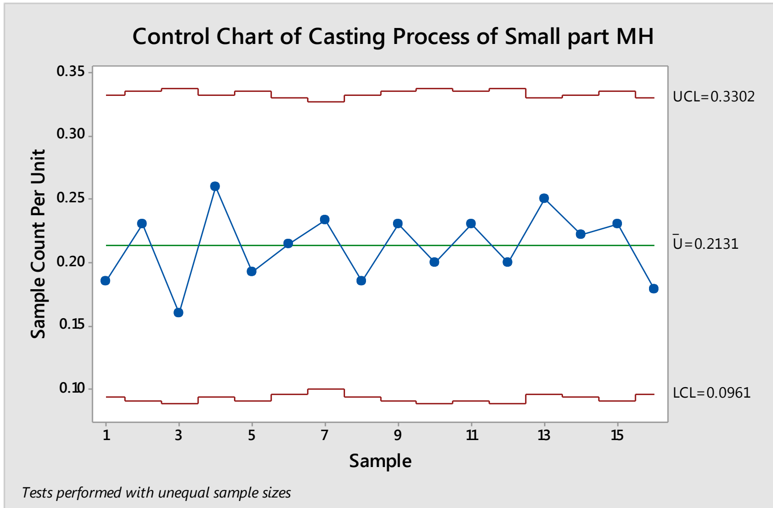


Figure 4.3 Control chart of casting process of small part MH

Figure 4.3 shows the control chart of production of small part in casting process. The centerline of control chart is 0.2131. There is no pattern in the chart, and also there is no value plotted out of control limits. It can be seen that the performance of process casting of small part is stable or in-controlled.

Ū or center line can be calculated using formula 2-3

$$\bar{U} = \frac{455}{2135} = 0.2131$$

U_i can be calculated using formula 2-4

$$U_i = \frac{25}{135} = 0.1852, \text{ and so on}$$

UCL can be calculated using formula 2-5

$$UCL = 0.2131 + 3\sqrt{\frac{0.2131}{135}} = 0.3302 \text{ and so on,}$$

LCL can be calculated using formula 2-6

$$LCL = 0.2131 - 3\sqrt{\frac{0.2131}{135}} = 0.096 \text{ and so on.}$$

After control chart indicates that the process is stable and in-controlled, the further phase of DMAIC can be done. The next step in measure phase is measuring quality level of small part MH in current condition. The data from quality control division about small part MH is required to measure the current quality level. Those data could be used to calculate defect per million opportunity (DPMO), sigma level, and conducting Pareto chart of small part MH. Table 4.10 shows the defect categories in casting process.

Table 4.10 Small part defect category

No.	Type	Number of small part	Number of defect	Defect Categories				Defect percentage
				Unfilled	Shrinkage	Flash	Crack	
1	MH J	676,586	155,318	23,298	82,319	26,404	23,298	23%
2	MH K	297,513	68,591	13,718	34,296	13,718	6,859	23%
3	MH 939-40	72,352	9,947	2,188	5,471	1,293	995	14%
4	MH 933-34	10,641	1,531	230	735	306	260	14%
5	MH 933-34-B	15,080	3,187	637	1,275	637	637	21%
Total		1,072,172	238,574	40,071	124,095	42,359	32,049	19%

Table 4.10 shows the categories of defect. There are four kind of defects which are unfilled, shrinkage, flash, and crack. The highest defect of small part MH is shrinkage with total amount of 124,095 defect point. Measure this categories of defects aim to clarify the major defects which needed to be reduced.

After defined the categories of defects occurred in casting process, the next step is conducted Pareto Chart. Pareto Chart aims to identify the utmost occurring defects and prioritize the most critical problem which was required to be tackled (Ploytip, 2013). With the data in table 4.7, which is defect categories in casting process, such as unfilled, shrinkage, flash, and crack, there is a percentage of defects for every type of defect. From the Pareto chart the percentage of every category of defect can be calculated. Unfilled contributes 13.4% from the total defects in casting process, while shrinkage contributes the highest defect rate which is 52%. Meanwhile flash contributes 17.8% and crack contributes 16.8% from total defects in casting process. The detail of Pareto Chart is shown in figure 4.4. Then because shrinkage had the biggest amount of defect among another category. So this research will be focused on reduction of the shrinkage.

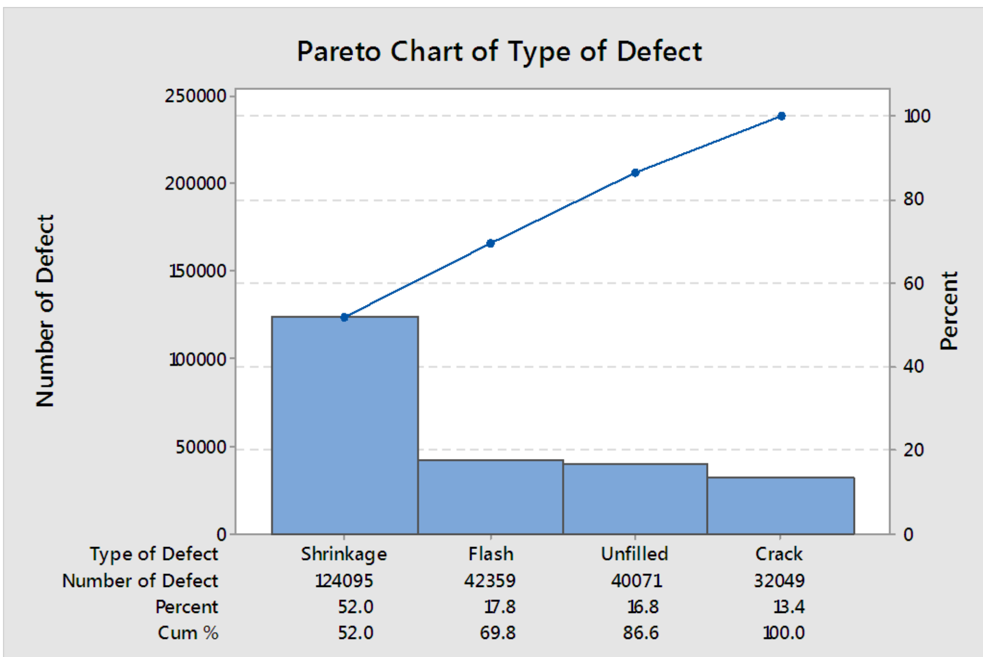


Figure 4.4 Pareto Chart of Small Part Defect

After defining the total number of defects and defined the utmost occurring defects, the DPMO and sigma level of the small part MH casting process were calculated (Ploytip, 2013). Before calculate the DPMO level of shrinkage, the first thing to done is calculating the defect percentage. To obtain the defect percentage, total amount of defect product should be divided by the total number produce and then times 100%. Below is an example of calculating defect percentage. The calculation of defect percentage below is using formula (2-1)

$$Defect\ Percentage = \frac{124,095}{1,072,172} * 100\% = 12\%$$

After obtained the defect percentage, the next step is calculating Defect Per Million Opportunity (DPMO). DPMO is obtained by multiplying one million with number of shrinkage defect product divided by number small part produce multiplying by number of opportunity per unit (Unfilled, Shrinkage, Flash, and Crack). The calculation is shown below. The calculation of DPMO below is using formula (2-2)

$$DPMO = \frac{1,000,000 * 124,095}{1,072,172 * 4} = 28,936$$

The last step of calculating sigma level is calculating sigma level by using Six Sigma Calculator in Microsoft Excel. The sigma level of current condition of small part MH is obtained in figure 4.5.

Six Sigma Calculator

Defects	124.095
Opportunities	1.072.172
Defect Opportunities per unit	4

DPMO	28935.42
Sigma Level	3.4

Six Sigma Table:

1	690.000
2	308.000
3	66.800
4	6.210
5	320
6	3.4

Figure 4.5 Sigma level shrinkage

The formula of sigma level

-norm.s.inv(DPMO/1,000,000)+1.5

From figure 4.5 above sigma level for 124,095 shrinkage defects out of 1,072,172 total number of units produced with 4 defect opportunities and with DPMO of 28,935 is 3.4. Since the sigma level of current condition is 3.4 so, it can be concluded that casting process needs to be improved.

4.4.3 Analyze

After known that shrinkage has the highest defect rate among another defects, next is move to the next phase of DMAIC which is analyze phase. This phase aims to determine the root cause of shrinkage in casting process of small part MH by using cause and effect diagram also called as fish-bone diagram. Cause and effect diagram providing a relationship between and effect and all possible causes of such effect (Ross, 2004). The diagram helps to uncover root causes and provide ideas for further improvement (Dale *et al.*, 2007).

To find the root cause of shrinkage in casting process, problem identification have to be done first. Another purpose of problem identification is to know the actual parameter setting in casting process and the procedures. To find the root cause, interviewing the workers and supervisor is conducted. In current condition, PT. LOL only have 3 casting machine with 6 cavity in each machine. With the high demand of small part MH the worker is busy with casting, so the probability of defects is high. After conducted interview with workers and supervisor, the root cause that can be found for shrinkage can be categorized in four factors which are machine, method, environment, and man. For shrinkage, material cannot be categorized as the factor because material cannot affect shrinkage defect. Figure 4.6 is shown the detail of cause and effect diagram of all causes in casting defect.

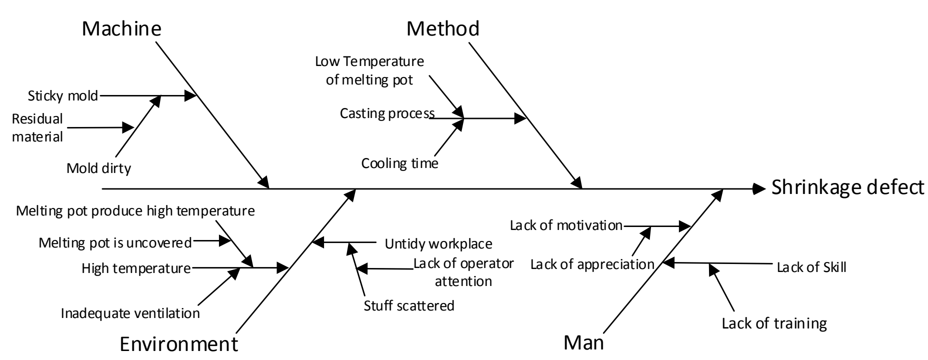


Figure 4.6 Cause and effect diagram

After conducting cause and effect diagram, it is known that the causes of casting defects especially for shrinkage category is caused by several things such as method, man, machine and environment. For the method, it is known that combination of temperature and cooling time has and direct effect to shrinkage. The parameter setting in the casting have to measure well, if the temperature of melting-pot is below procedure it can the melted lead will hard to casting and if the temperature is above the procedure it will need more time for cooling time and of course another problem will occur which is the demand could not be fulfill. The temperature of melting-pot and cooling time have to be adjusted well to produce good small part MH. Man factor as one of cause of defect in casting process happened because the workers is lack of training due to casting, it leads to the defect in casting and also lack of motivation that leads to the worker consistency and concentration. For machine factor, if the mold is sticky then, it will be hard to release small part MH from the mold, so the defect will be occured. The caused of sticky mold is because the mold is not spray with chemical substance. The main cause of sticky mold is because, operator is not aware of the mold, the operator have to sprayed the mold with chemical substance, so the mold will not be sticky. Lastly factor that influence the casting process is environment factor. Due to casting process that leads to the high temperature, the workplace need adequate ventilation to decrease the temperature in casting workplace, as the main source of high temperature, melting pot has to be covered well, so the temperature of melting pot will not affect the workplace. Another cause from environment factor untidy workplace, there are so many stuff scattered such as box and cable around worker that makes trouble to the worker while casting small part MH.

4.4.4 Improve

As the one of DMAIC phase, improve phase plays an important role for this research. In this research improvement will be applied to reduce the defect rate in casting process, especially for shrinkage defect. After cause and effect diagram is constructed in analyze phase, here are some proposed improvement that can be done. Each category of factor had its own proposed improvement, it can be seen in table 4.11.

Table 4.11 Proposed improvement

Category	Failure potential	Potential failure causes	Improvement
Method	Casting process	Low temperature of melting-pot	Defined proper temperature of melting-pot
		Rapid cooling time	Defined proper cooling time for casting process
Environment	High temperature	Inadequate ventilation	The company should provide cooling fan and make adequate ventilation
		Melting is not covered	Company have to make covered for melting pot
	Untidy workplace	Lack of operator attention	Conduct 5S every week
Man	Lack of motivation	Lack of appreciation	Given appreciation for the worker who can reach the production target by given the worker extra money as a bonus
	Lack of skill	Lack of training	Operator should get additional training about casting for every 4 months
Machine	Sticky mold	Residual material	Make a checklist sheet for checking the mold

Table 4.11 explains that after the discussion with head of Head of Quality Control division, and production manager due to the cause and effect diagram that already made, the one of the root causes of shrinkage defect is there is direct effect of temperature of melting-pot and cooling time. So the improvement in this case will be focused on defining the best parameter of temperature and cooling time in casting process as the priority. Experimental design is chosen to find the best parameters. Experimental design was used to investigate whether the assumed correlation was statistically significant (Ploytip, 2013). Two-way ANOVA will be constructed due to the two factors that responsible for shrinkage defect occur.

4.4.4.1 Parameter setting as design factor

For this case the parameter setting is defined as controllable factors which is an independent factor that can be changed according to the requirement in the experiment such as temperature of melting-pot and cooling time. And uncontrollable factors which is a dependent factor that cannot be changed, the example of uncontrollable factors are weather condition, natural disaster, and etc. The research is set by two variables which are melting-pot's temperature and cooling time. These two variables are the main variables for the quality in casting process. Two variables that mention earlier were investigated with four different parameters of temperature: 440^{o}C, 445^{o}C, 450^{o}C, 455^{o}C as factor and four different parameters of cooling time: 6s, 7s, 8s, and 9s as factor, the level for this experiment is four for each factor. These parameters were defined based on the process knowledge and experience of the Head of Quality Control division and Production manager.

4.4.4.2 Pre-Test design of experimental

As the statement before, the variables that used for testing two-way ANOVA were temperature and cooling time. Since performing a large number of trial for two-way ANOVA can be expensive and also time consuming. The experiment could be replicated five time for each combination of factors, it was 1,625 units of small part MH where collected for every replication. So this trial would had 80 replications. The result of experiment is shown in table 4.12.

Table 4.12 Number of small part defect in experiment

Cooling time (s)	order	Temperature (^{o}C)				Total number of defects (pcs)
		440	445	450	455	
6	1	160	172	153	147	3,186
	2	142	183	150	175	
	3	155	165	130	168	
	4	145	160	140	187	
	5	174	185	155	140	
7	1	142	123	124	142	2,815
	2	150	142	140	124	
	3	152	155	132	152	

	4	140	163	134	134	
	5	132	146	144	144	

Table 4.13 Number of small part defect in experiment (Cont'd)

8	1	110	120	80	110	2,051
	2	120	102	79	90	
	3	115	123	75	102	
	4	121	111	90	108	
	5	103	120	83	89	
9	1	120	100	100	110	2,110
	2	115	120	99	103	
	3	102	101	102	102	
	4	105	100	95	113	
	5	110	110	103	100	
Total number of defects (pcs)		2,613	2,701	2,308	2,540	10,162

Table 4.12 and table 4.13 presents the experiment and the result obtained for trial. The result is number of defect for each combination of factor, in terms of shrinkage defects. For instance, as it shown that if the melting-pot's temperature reach 440^{o}C and the cooling time is 6 seconds, 160 shrinkage small part MH out of 1,625 unit inspected were identified in replication one, where are in replication two, 142 shrinkage small part MH were found, and so on. The highest number of defects occur when the cooling time is set in 6 seconds which had 3186 units. It also happens in the temperature of 445^{o}C which is 2701 units.

4.4.4.3 Estimate factor effect

Estimate factor effect is useful to give information of statistical analysis. Using statistical software to analyze the factorial effect is more accurate. After conducting statistical analysis about factor effect, the result showed that the R-square for this experiment was 88.65% which indicates that the model explains all the variability of the response data around its mean. The details of factor effect will be explained in figure 4.7.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
10.2210	88.65%	85.99%	82.27%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	127.02	1.14	111.16	0.000	
Cool time					
6	32.27	1.98	16.31	0.000	1.50
7	13.73	1.98	6.93	0.000	1.50
8	-24.47	1.98	-12.37	0.000	1.50
temperature					
440	3.62	1.98	1.83	0.072	1.50
445	8.03	1.98	4.05	0.000	1.50
450	-11.63	1.98	-5.87	0.000	1.50
Cool time*temperature					
6 440	-7.73	3.43	-2.25	0.028	2.25
6 445	5.67	3.43	1.66	0.103	2.25
6 450	-2.07	3.43	-0.61	0.547	2.25
7 440	-1.18	3.43	-0.34	0.733	2.25
7 445	-2.97	3.43	-0.87	0.389	2.25
7 450	5.68	3.43	1.66	0.103	2.25
8 440	7.63	3.43	2.22	0.030	2.25
8 445	4.62	3.43	1.35	0.182	2.25
8 450	-9.53	3.43	-2.78	0.007	2.25

Figure 4.7 Estimate factor effect

From the output from statistical software above, it could be seen how each factor effects the shrinkage defects and also the combination of factors that affects the process. The influence of each factor is determined by the coefficients, t-value and p-value needs to be examined in order to know which factors give significant influence to the shrinkage. If the p-value is less than 0.05, it means that the factor influence the shrinkage. So it can be concluded that all of the types of cooling time that had been set for this trial had significant influence to the shrinkage due to each P-value that less than 0.05. For the temperature, 440^{o}C did not influence the shrinkage because of its P-value that higher than 0.05, while 445^{o}C and 450^{o}C had significant influence to the shrinkage. The combination between cooling time and temperature have four combination that have signification influence to the shrinkage which are 6 seconds of cooling time with 440^oC of temperature, 8 seconds of cooling time with 440^oC of temperature, and 8 seconds of cooling time with 450^oC of temperature.

4.4.4.4 Initial model of response

After the factor effect had been calculated, and the coefficient appears in the statistical software, then the initial model of response can be constructed. Initial model described the coded unit by estimates of coefficients and factors for represents response.

```
shrinkage = 127.02 + 32.27 Cool time_6 + 13.73 Cool time_7 - 24.47 Cool time_8
            + 3.62 temperature_440 + 8.03 temperature_445
            - 11.63 temperature_450 - 7.73 Cool time*temperature_6 440
            + 5.67 Cool time*temperature_6 445 - 2.07 Cool time*temperature_6 450
            - 1.18 Cool time*temperature_7 440 - 2.97 Cool time*temperature_7 445
            + 5.68 Cool time*temperature_7 450 + 7.63 Cool time*temperature_8 440
            + 4.62 Cool time*temperature_8 445 - 9.53 Cool time*temperature_8 450
            + 1.27 Cool time*temperature_9 440 - 7.32 Cool time*temperature_9 445
            + 5.92 Cool time*temperature_9 450
```

Figure 4.8 initial model of response

Interpretation of the result in figure 4.8 as follow:

- The shrinkage will be increased by 32.27 when the cooling time is set in 6 seconds with a condition where other factor which is temperature have no influence.
- The shrinkage will be increased by 13.73 when the cooling time is set in 7 seconds with a condition where other factor which is temperature have no influence.
- The shrinkage will be decreased by 24.47 when the cooling time is set in 8 seconds with a condition where other factor which is temperature have no influence.
- The shrinkage will be increased by 3.62 when the temperature is set in 440^oC seconds with a condition where other factor which is cooling time have no influence.

- The shrinkage will be increased by 8.03 when the temperature is set in 445^{o}C seconds with a condition where other factor which is cooling time have no influence.
- The shrinkage will be decreased by 11.63 when the temperature is set in 450^{o}C seconds with a condition where other factor which is cooling time have no influence.
- The shrinkage will be decreased by 7.73 when the cooling time is set in 6 seconds and the temperature is set in 440^{o}C.
- The shrinkage will be increased by 5.67 when the cooling time is set in 6 seconds and the temperature is set in 445^{o}C.
- The shrinkage will be decreased by 2.07 when the cooling time is set in 6 seconds and the temperature is set in 450^{o}C.
- The shrinkage will be decreased by 1.18 when the cooling time is set in 7 seconds and the temperature is set in 440^{o}C.
- The shrinkage will be decreased by 2.97 when the cooling time is set in 7 seconds and the temperature is set in 445^{o}C.
- The shrinkage will be increased by 5.68 when the cooling time is set in 7 seconds and the temperature is set in 450^{o}C.
- The shrinkage will be increased by 7.63 when the cooling time is set in 8 seconds and the temperature is set in 440^{o}C.
- The shrinkage will be increased by 4.62 when the cooling time is set in 8 seconds and the temperature is set in 445^{o}C.
- The shrinkage will be decreased by 9.53 when the cooling time is set in 8 seconds and the temperature is set in 450^{o}C.
- The shrinkage will be increased by 1.27 when the cooling time is set in 9 seconds and the temperature is set in 440^{o}C.
- The shrinkage will be decreased by 7.32 when the cooling time is set in 9 seconds and the temperature is set in 445^{o}C.

- The shrinkage will be increased by 5.92 when the cooling time is set in 9 seconds and the temperature is set in 450°C.

4.4.4.5 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) has a purpose to calculate the effects of the factors and interactions. Therefore, for this research two-way ANOVA analysis indicated that there was a correlation between melting-pot's temperature and cooling time at a significant level $\alpha = 0.05$. As the result, ANOVA helped to statistically concluded that both temperature and cooling time influenced the amount of shrinkage MH. If the p-value is less that α, it means reject H_0. Then if the p-value is higher than α, it means accept H_1. Figure 4.9 is shown the result of ANOVA calculation for trial.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cool time	3	45848	15282.7	146.29	0.000
temperature	3	4254	1417.9	13.57	0.000
Cool time*temperature	9	2130	236.7	2.27	0.028
Error	64	6686	104.5		
Total	79	58918			

Figure 4.9 ANOVA

ANOVA can be evaluated with two value: F-value and P-value. By examining P-value from ANOVA, the p-value of each factor indicated different effect to shrinkage. If the P-value less than α (α=0.05), it means there is different in the influence from the treatment to shrinkage. After conducting ANOVA analysis, the F-value and P-value for each factor had been found. F-value is used to evaluate the hypothesis that once formulated. When the F-value of factor is higher than F critical, it means that H_0 is rejected, while if the F-value is less than F critical, it means that H_1 is accepted. It similar for P-value that already explained before. Table 4.14 shows the hypothesis for the experiment

Table 4.14 Hypothesis testing

H	Hypothesis	Decision
H_0	There is no significant effect between each type of cooling time	Reject H_0 $0 < 0.05$
H_1	There is significant effect between each type of cooling time	
H_0	There is no significant effect between each type of cooling time	Reject H_0 $0 < 0.05$
H_1	There is significant effect between each type of cooling time	
H_0	There is no significant effect between each type of cooling time	Reject H_0 $0.028 < 0.05$
H_1	There is significant effect between each type of cooling time	

As the table 4.14 seen above, the hypothesis are evaluated based on P-value. For cooling time, because it had 0 in P-value so it can be stated that H_0 for cooling time is rejected because it less than α (α=0.05). Similar with cooling time, temperature also got 0 in P-value which means H_0 is rejected. As well as cooling time and temperature, the combination between both factors also got 0.028 in P-value, which means reject $H_{0.}$ Here are the brief explanations about the hypothesis that accepted:

- Cooling time factor had P-value less than α, so it indicated that there are differences in the influence of those four types of cooling time to the shrinkage.
- Temperature factor had P-value less than α, so it indicated that there are differences in the influence of those four types of temperature to the shrinkage.
- Interaction between cooling time and temperature had P-value less than α, so it indicated that there are differences in the influence of interaction type of cooling time and temperature toward shrinkage.

4.4.4.6 Analyze residual

To see the assumption from ANOVA is fulfilled or not conducting residual analysis is the best way. Residual analysis frequently used to evaluate validity of assumptions of statistical models. For this research, the researcher used common graphic tools for residual analysis which is residual plot. Residual plots consist of three assumptions, which are normality of residual assumption, residual independency assumptions, and residual independency. The graph of residual plots can be seen in figure 4.10

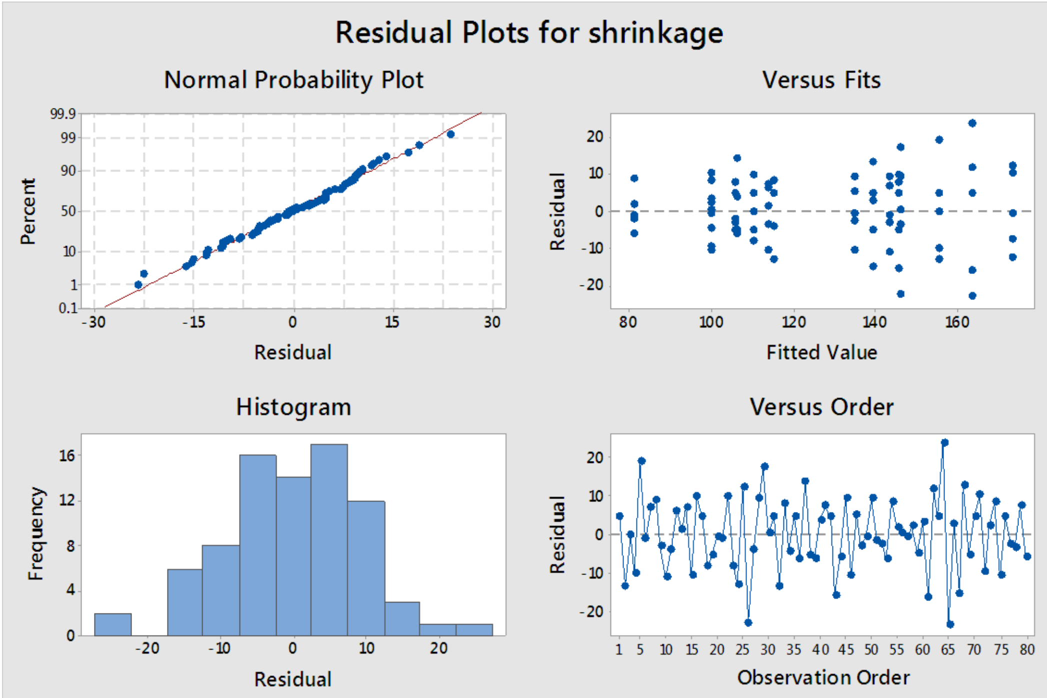


Figure 4.10 Residual plots for shrinkage

Figure 4.10 explains that the graph forms a pattern of the points which follows linear pattern, means that the residual is normally distributed. Normality of residual assumption could be seen from normal probability plot. In the versus fits graph, it is used to see the homogenity of the residual. It is called homogenity of residual because the points are spreaded without forming any pattern. In versus order, the independency among the residual can be seen. The points in the graph are not following any pattern and tend to spread randomly. Because of the phenomenon in the graph, it can be concluded that the independency assumption from ANOVA is fulfilled.

4.4.4.6 Main effect plot

Main effects plot is used to examine differences between level means for one or more factors. A main effects plot graphs the response mean for each factor level connected by a line. A line connected the points for each variable. The line that connected the means can be interpreted as:

- When the line is horizontal (parallel to the axis), there is no main effect present. The response mean is the same across all factor levels.
- When the line is not horizontal, there is main effect present. The response mean is not the same across all factor levels. The steeper the slope of the line, the greater the magnitude of the main effect. The graph of main effect plot can be seen in figure 4.11.

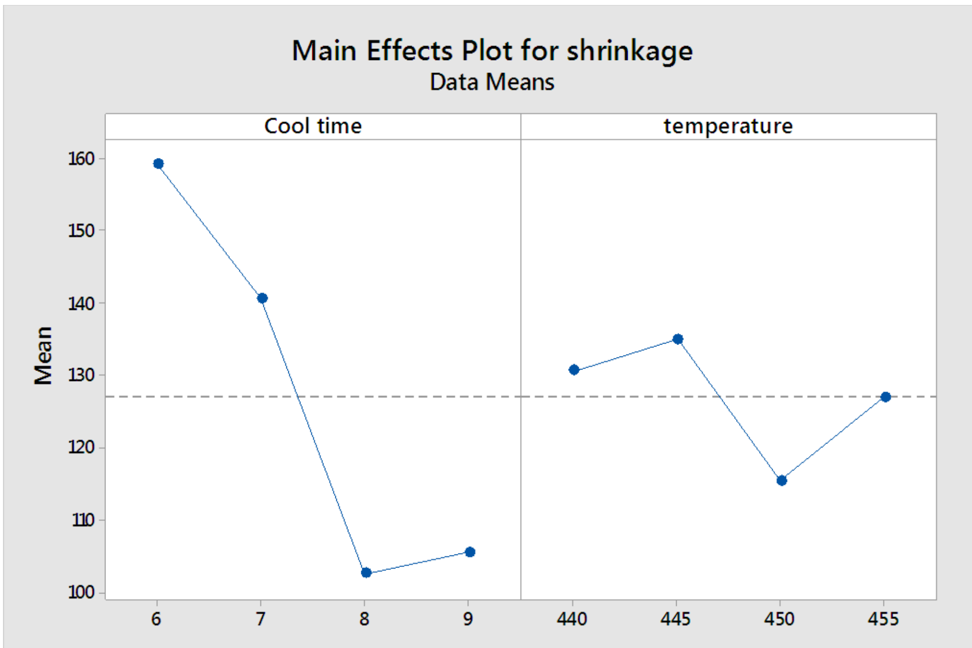


Figure 4.11 Main effect plot

From the figure 4.11 above about main effect plot, the result of main effect plot can be interpret as:

- Cooling time

  From four types of cooling time factor which are 6, 7, 8, and 9 seconds. The highest average shrinkage is occurred in 6 seconds while in other hand the lowest average shrinkage is occurred in 8 seconds. All the types of cooling time had different average of shrinkage.
- Temperature

From four types of temperature factor which are 440, 445, 450, 450°C. The highest average shrinkage is occurred in 440°C while in other hand the lowest average shrinkage is occurred in 450°C. All the types of cooling time had different average of shrinkage.

4.4.4.7 Interaction plot

To test for two-way interactions (often thought of as a relationship between an independent variable and dependent variable, moderated by a third variable). First run a regression analysis, including both independent variables and their interaction term. Interaction plot displays the level of one variable on the X axis and has a separate line for the means of each level of the other variable. The Y axis is the dependent variable. Interaction plot between temperature and cooling time can be seen in figure 4.12.

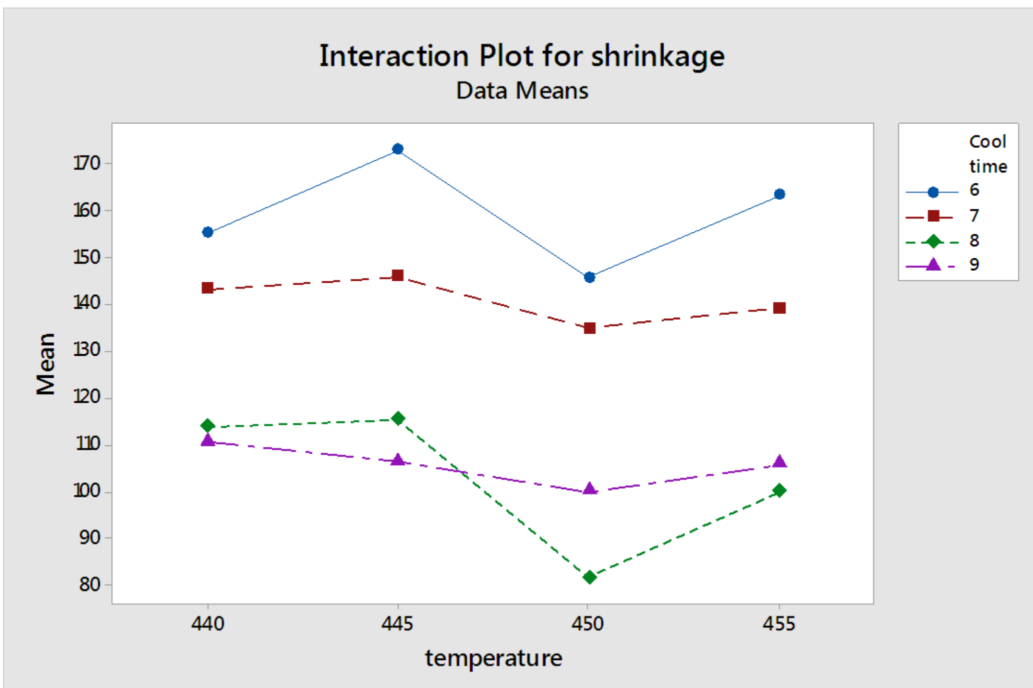


Figure 4.12 Interaction plot

Based on the graph above figure 4.12 about interaction between Temperature and Cooling time, the highest amount shrinkage appeared in temperature 445°C with cooling time of 6 seconds. The lowest amount of shrinkage is in temperature 450°C with 8 seconds of cooling time. 9 seconds of cooling time had very balance output for this trial while combined with all types of temperature. Response optimization due to new parameters for shrinkage defect is shown in figure 4.13.

Optimization Plot

Response Optimization: shrinkage

```
Parameters

Response   Goal      Lower  Target  Upper  Weight  Importance
shrinkage  Minimum              81    161       1           1


Solution

          Cool                   shrinkage     Composite
Solution  time  temperature            Fit  Desirability
1         8     450                   81.4         0.995


Multiple Response Prediction

Variable     Setting
Cool time    8
temperature  450


Response     Fit  SE Fit        95% CI             95% PI
shrinkage  81.40    4.57  (72.27; 90.53)  (59.03; 103.77)
```

Figure 4.13 Response optimization

Response optimization helps to identify the combination of variable settings that jointly optimize a single response or a set of responses. According to the result from response optimization above in figure 4.13, it is known that the factor that can minimize the shrinkage to around 50% from the current condition. The factors that can achieve the objective are 8 seconds of cooling time with 450^{o}C temperature of melting-pot.

4.4.5 Control

Control is the last phase on DMAIC approach. In order to achieve the objective of this research, there are several control tools that can be used. The common tools for control the process and improvement are checklist sheet and job evaluation. All these tools expected to be able in sustaining the improvement phase.

4.4.5.1 Checklist Sheet

Checklist sheet is one of common tools that can be used for controlling the process. It aims to continuously sustaining the improvement on the process flaws. Checklist sheet necessarily needed to keep the quality of casting in a good state. Checklist sheet is filled daily by the operator before casting process started. For casting process checklist sheet aims to check whether the machine, equipment and material are good.

Checklist Sheet During Investigation

Date		:
Name		:
Division		:
No	Subject	Checked
1	Document	
1.1	Work Order	
1.2	SOP	
2	Melting Pot	
2.1	Setting temperature	
3	Mold	
3.1	Mold sprayer	
3.2	Setting timer	
4	Material	
4.1	Lead bars	
4.2	*Gumrosin*	
5	Safety	
5.1	Masker	
5.2	Heat resistance gloves	
5.3	Safety shoes	
6	Equipment	
6.1	Marker	

Checker	Approval

Figure 4.14 Checklist template for investigation

Figure 4.14 is the template of checklist sheet during experiment. Checklist sheet has some purposes which are controlled the document, the condition of machine, material, safety equipment, and other. Before the casting process begin, the inspector have to check the work document such as Work Order, and SOP. The inspector also have to check the condition of melting pot which is the temperature of melting pot. After check the temperature of melting pot, next is checking the mold, in order to get a maximum output in the process, the timer has to set to 8 seconds based on the experiment before. Mold sprayer also has to be checked for mold. The inspector expected to check the materials for producing small part such as lead bars and coating material named Gum Rosin. Then, the inspector has to check the safety and equipment for manufacturing small part which are masker, casting gloves, safety shoes and marker. The inspector have to fill the checklist sheet daily during investigation.

4.4.5.2 Job Evaluation

In order to maintain the casting quality, the condition of casting process had to be stable. The management of PT. LOL had to evaluate the work result that already done by the operator to see whether the improvement already optimally done in order to minimize the number of defect in casting process. Job evaluation can be done by two ways, which are morning briefing and job review.

- Morning briefing

  As the name of morning briefing, it means in the morning a briefing had to be conducted that the operator aims to sharing the condition and guiding on the current job. Morning briefing is done twice a week, on Monday, Wednesday. On Monday, the briefing is delivered by general manager of QC department and the member that required to attend the briefing are: Production and QC. The purposes of morning briefing are given the guidance and motivating the staffs to keep the morale of each staff high. Wednesday briefing is expected to be delivered by each manager on QC and Production department, and explaining technical aspects on the current job after improvement. Wednesday briefing is expected for all the members to discuss the problems that are found by every department, and find the solution for the problems.

- Job Review

  Job review is done in every Friday afternoon that are leads by every manager QC and Production department before the working hours is finished. The purpose of the job review is to discuss the problems faced on the current week and to create a plan for the next week. It is expected by reviewing the job, the operator's vision and management are in accordance to produce good quality of product in every job.

4.5 Comparison before and after new parameters

After finding the good parameters for casting process, next is analyze how the new parameters affect the defect number in casting process. The comparison between the "before and after" setting the new parameters aims to indicate that the optimum parameters identified in the experiment improved the gloves manufacturing process by reducing the defect (Ploytip, 2013). And also the important things is reduce the loss caused by defect in casting process. In order to avoid disrupting production and taking into consideration that the previous experiment had already determined the optimum melting-pot's temperature and cooling time, a sample size of 16, 250 units of small part MH was taken as a base for the investigation, because implementing the new parameters based on calculation before will time consume. All the aspects for the improvement had to be compared with the condition before improvement. Based on the investigation, the result of new parameters is shown in table 4.15 and table 4.16.

Table 4.15 Defect percentage based on investigation

No.	Type	Number of Checking	Number of defect	Defect Categories				Defect percentage
				Unfilled	Shrinkage	Flash	Crack	
1	MH J	3,250	423	85	161	93	85	13%
2	MH K	3,250	390	78	195	39	78	12%
3	MH 939-40	3,250	228	57	102	34	34	7%

Table 4.16 Defect percentage based on investigation (Cont'd)

4	MH 933-34	3,250	260	52	104	52	52	8%
5	MH 933-34-B	3,250	390	59	137	98	98	12%
Total		16,250	1,690	330	698	316	346	10%
Defect percentage for each category				2%	4%	2%	2%	

Table 4.15 and table 4.16 explain that defect percentage of MH J is 13%, defect percentage of MH K is 12%, defect percentage of MH 939-40 is 7%, MH 933-34 is 8% and MH 933-34B is 12%. The highest percentage of defect occurred in MH J for about 13% and MH 939-40 has the lowest percentage of defect, which is 7%. The percentage of shrinkage in small part MH based on investigation is 4 %, while the other categories which are unfilled, flash, and crack are 2% each.

4.5.1 Defect percentage before versus after improvement

The improvement aims to reduce percentage of defect. The purpose of this comparison is to know percentage defect after improvement. Table 4.17 shown defect percentage before versus after improvement.

Table 4.17 Small part MH defect percentage before vs new parameters

No.	Type	Defect Percentage	
		Before	After
1	MH J	23%	13%
2	MH K	23%	12%
3	MH 939-40	14%	7%
4	MH 933-34	14%	8%
5	MH 933-34-B	21%	12%
	Total	19%	10%

Table 4.17 shows that new parameters setting in casting process has reduce the number of defect in every type of small part MH, before implementing new parameters, MH J and MH K have 23% of defect percentage while in new parameters the defect percentage on both are 13% and 12% respectively. Overall the total defect

percentage of small part MH has reduce by 55% from 19% to 10%. The graph of comparison between before and after improvement can be seen in figure 4.15.

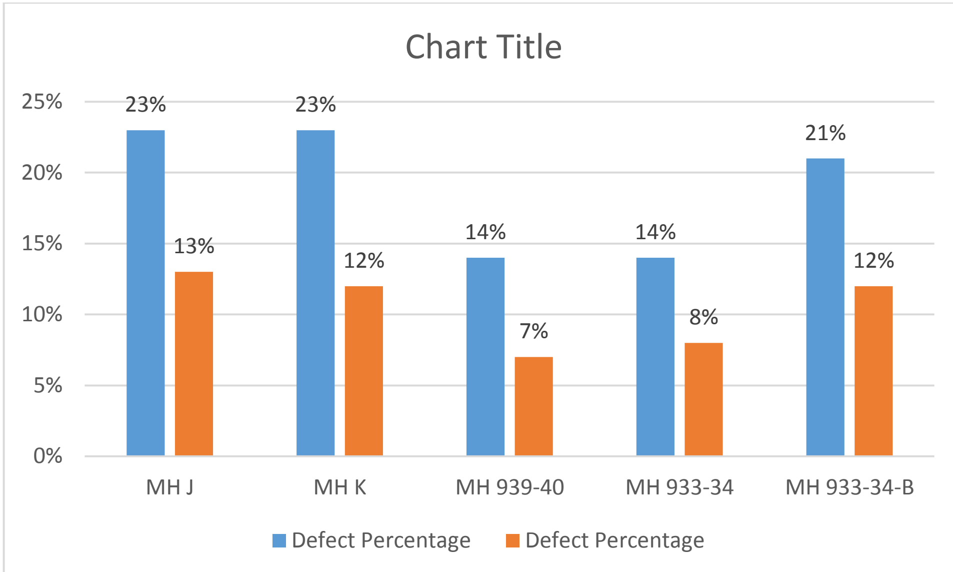


Figure 4.15 Defect percentage of small part before vs after

The figure above shows that after investigating new parameters, it is show that defect percentage on every type of small part MH has reduce significantly. For instance, in MH 939-40 the defect percentage has reduce by 50% from 14% to 7% and in MH J the defect percentage reduce by 43.5%. Table 4.18 shows the percentage in every defect categories before and after new parameters.

Table 4.18 Small part defect percentage before and after new parameters

Type of Defect	Percentage of defect before new parameters	Percentage of defect after new parameters
Shrinkage	12	4
Unfilled	4	2
Flash	4	2
Crack	3	2

According to table 4.18, if the new parameters are applied, the shrinkage will reduce drastically from 12% to 4%, in other words the new parameters succeed to reduce the shrinkage defect. Other categories of defect also reduced, for unfilled the percentage reduce by 2% from 4% to 2%. Same as unfilled, flash also reduce around 2%. Another category which is crack reduce 1% from 3% to 2%. The graph is shown in figure 4.16.

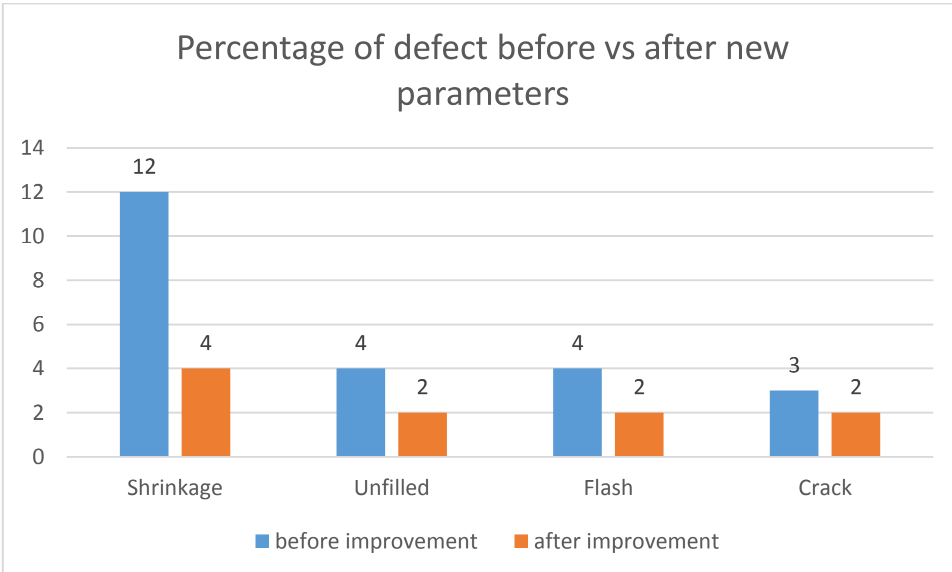


Figure 4.16 Comparison between before and after improvement

Figure 4.16 explains that number of percentage of all defect categories has reduce by implementing new parameters. Shrinkage has significantly reduce by 67%, unfill and flash has reduce by 50% and crack has reduce by 33%.

4.5.2 Sigma level before versus after improvement

The new parameters for improvement aims to reduce the sigma level in shrinkage. It is not only sigma level but the improvement is expected to reduce the (DPMO). The purpose of this comparison is to know the sigma level and DPMO after improvement. Table 4.19 is shown sigma calculation before versus after improvement.

Table 4.19 Sigma calculation before and after new parameter

Before		After	
DPMO :	28,936	DPMO :	10,739
Sigma Level :	3.4	Sigma Level :	3.8

Table 4.19 shows sigma level after applied new parameters for shrinkage, before implementing six sigma in shrinkage the DPMO value is 28,936 with sigma level 3.4. After applied new parameters the DPMO value had decreased to 10,739. The sigma level had increased from 3.4 to 3.8. It shows that the improvement process can increase sigma level and decreased the number of defect product.

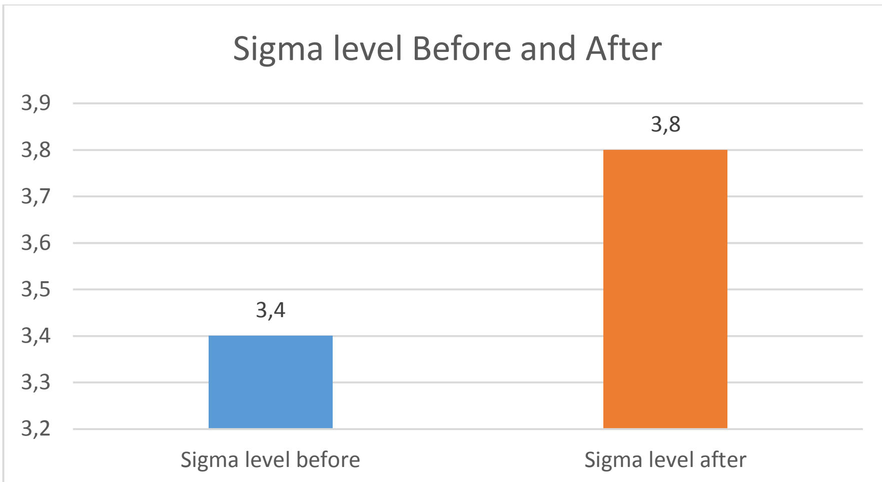


Figure 4.17 Comparison of sigma level before and after new parameters

Figure 4.17 shows the comparison of sigma level before and after new parameters. New parameters that got from improve phase in DMAIC methodology have effectively increase the sigma level, from 3.4 to 3.8.

4.5.3 Cost Analysis before and after improvement

After comparing the percentage of defect before and after improvement and sigma level before and after applied new parameters of shrinkage. Now the last aspect that had to be compared is cost loss before and after improvement. Because implementing the proposed improvement will time consume, so the cost analysis before and after improvement was conducted by simulation based on data from investigation. The total loss is calculated based on small part MH before improvement and will be compared with small part MH after improvement The purpose of comparing the total loss is to know how much money that the company can save due to the improvement.

Table 4.20 shows the rework cost per month due to defect product before new parameters.

Table 4.20 Total loss before improvement

Type	Number of defect	Weight (gram/pcs)	Total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost (IDR)
MH 928 J	155,318	55	8,524	2,088,344	7,296,417	2,979,047	12,363,808
MH 928 K	68,591	55	3,764	922,247	3,222,219	1,315,596	5,460,062
MH 939-940	9,947	67	670	164,048	573,162	190,787	927,997
MH933-34	1,531	49	74	18,228	63,685	29,365	111,278
MH933-34-B	3,187	49	155	37,944	132,571	61,128	231,642
Total	238,574		13,187	3,230,810	11,288,054	4,575,923	19,094,787
Average per month	59,644		3,297	807,702	2,822,014	1,143,981	4.773.697

Table 4.20 explains that in current condition or in other words before new parameters was found, the total loss in rework small part MH per month is IDR 4,773,697. In a year the total loss of rework small part MH will be IDR 57,284,364. Table 4.21 shows the total loss expected after new parameters in a month.

Table 4.21 Total loss expected after implement new parameters in a month

Type	Number of defect	Weight (gram/pcs)	total weight (Kg)	Electricity IDR 245 / Kg	Gas IDR 856 / Kg	Man power IDR 7792 / Hour	Rework Cost (IDR)
MH J	21,898	55	1,204	295,076	1,030,958	105,002	1,431,035
MH K	8,925	55	491	120,264	420,189	42,796	583,249
MH 939-40	1,266	67	85	20,781	72,608	6,070	99,459
MH 933-34	213	49	10	2,557	8,934	1,021	12,512

MH 933-34-B	377	49	18	4,526	15,813	1,808	22,147
Expected total loss	32,679			443,204	1,548,501	156,697	2,148,403

Due to new parameters that can reduce 48% defects from current condition, table 4.17 shows the rework cost. If the company implementing new parameters in the casting process, it is expected that the total rework cost will reduce to IDR 2,148,403 per month. After calculating the total loss per month before the improvement and after improvement. It can be seen that the loss because of defect in casting process at small part MH before the improvement was IDR 4,773,697 in a month. And after the improvement, total loss due to investigation because of defect only IDR 2,148,403 in a month. So the total cost saving due to improvement is shown below:

$$Cost\ Saving\ (IDR) = Total\ loss\ before - Total\ loss\ after$$

$$Cost\ Saving\ (IDR) = 4{,}773{,}697 - 2{,}148{,}403$$

$$Cost\ Saving\ (IDR) = 2{,}625{,}294$$

According to the calculation above about cost saving, the improvement is able to reduce the loss for about 55% or IDR 2,625,294 that caused by defect. Figure 4.18 shown the comparison of loss before and after improvement.

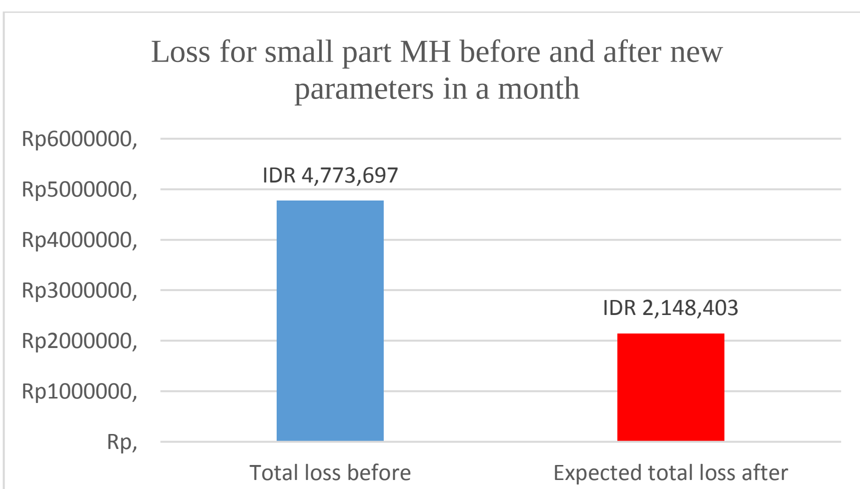


Figure 4.18 Total loss comparison before and after improvement

Figure 4.18 shows, if the new parameters are applied in casting process especially for small part MH. The loss that company obtained from defect product will reduce. In June-September 2016 before applied new parameters that got from two-way ANOVA analysis, the total loss from defect product of MH is around IDR 19,094,787, while if the new parameters are applied it is expected that the loss will reduce to IDR 8,592,654 for 4 months, or in a year the loss will reduce to IDR 25,780,836. The total loss expected from new parameters only calculated based on defect percentage after investigation.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the Six Sigma DMAIC methodology, the results are:

- Define

  It is found that the most number of defect is in small part MH.

- Measure

  Using pareto chart, it is show the utmost defect category that occured in small part MH is shrinkage. DPMO value and sigma level of shrinkage is 28,935 and 3.4 respectively.

- Analyze

  Using cause and effect diagram, the correlation between melting-pot temperature and cooling time leads to shrinkage defect.

- Improve

  By using two-way ANOVA, new parameters is found, the best parameters in casting process are 450^{o}C of melting-pot temperature and 8 seconds of cooling time.

- Control

  Checklist sheet and briefing are useful to control the improvement process. To monitor the process, control chart is needed.

- Six Sigma method that conducted for this research is capable to reduce the number of small part defect in casting process. The number of defect in casting process before conducting six sigma was 19% and after implementation using new parameters defect on small part has been decrease to 10%.

5.2 Recommendation

The recommendations from this research are:

1. The company has to give training to the worker in order to reduce the number of defect caused by worker.
2. All of the stuff that needed for casting process have to be available when it needed.
3. Giving appreciation to the worker is the best way to keep the motivation.
4. Recommendations for future research are conduct the research for small part for motorcycle battery in order to decrease the number of defect in casting process and better problem solving tool to conduct Six Sigma DMAIC method.

REFERENCES

Arita, T. and McCann, P., Regular Monthly Income By Wearing Your Shorts at The Comfort of Your, *Journal of International Management*, Vol. 8 No. 1, 2002, pp. 121-39.

Bezerra, C.I.M., Adriano, A.B.A., Placido, L.S. and Goncalves, M.G.S., MiniDMAIC: An Approach to Causal Analysis and Resolution in Software Development Projects, *Quality Management and Six Sigma.* August, 2010.

Degarmo, E. Paul, Black, J T., Kohser, Ronald A., *Materials and Processes in Manufacturing (9th ed.),* John Wiley & Sons, Inc, 2003, p. 277.

Garland, Nibler and Shoemaker, *Experiments in Physical Chemistry*, *6th Ed*., McGraw-Hill, Boston, 2003.

Greenhill, J.M. and Palmer, S.W., A Practical Approach to Iron Castings Quality Control, *The British Foundryman*, Vol. 68 No. 7, 1973, pp. 188-202.

Kumar, U.D., Nowicki, D., Ramirez-Marquez, J.E. and Verma, D., The optimal Selection of Process Alternatives in A Six Sigma Implementation, *International Journal of Production Economics*, Vol. 111 No. 2, 2008, pp. 456-467.

Kumar, Sushil, Improvement of Sigma level of a foundry: a case study, *The TQM Journal*, Vol. 25 Iss 1, 2013, pp. 29 – 43.

Maneesh Kumar, Jiju Antony, Christian N. Madu, Douglas C. Montgomery, Sung H. Park, Common Myths of Six Sigma Demystified, *International Journal of Quality & Reliability Management*, Vol. 25 Iss: 8, 2008, pp.878 – 895.

McAdam, R. & Evans, A., Challenges to Six Sigma in a High Technology Mass Manufacturing Environments, *Total Quality Management*, Vol. 15, Issue 6, 2004, pp. 699-706.

Mitra, Amitava, *Fundamentals of Quality Control and Improvement, 3rd ed.*, John Wiley and Sons, Inc., New Jersey, 2008.

Montgomery, D. C., *Design and Analysis of Experiments 7th edition*, John Wiley & Sons, Inc., New Jersey, 2009.

Moore, D.S., McCabe, G.P. and Craig, B.A., *Introduction to the Practice of Statistics, 7th ed.*, W.H. Freeman and Company, New York, NY, 2009.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R., *The Six Sigma Way: How GE, Motorola, and Other Top Companies are honing Their Performance*, McGraw-Hill, New York, 2000.

Ploytip Jirasukprasert Jose Arturo Garza-Reyes Vikas Kumar Ming K. Lim, A Six Sigma and DMAIC Application for The Reduction of Defects in A Rubber Gloves Manufacturing Process. *International Journal of Lean Six Sigma*. Vol. 5 Iss 1, 2014, pp. 2 – 21.

Pyzdek, T. and Keller, P.A., *The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels, 3rd ed.*, McGraw-Hill, New York, NY, 2010.

Ray, S. and Das, P., Six Sigma project selection Methodology, *International Journal of Lean Six Sigma*, Vol. 1 No. 4, 2010, pp. 293-309.

Reddy, G.P.P. and Reddy, V.V., Process Improvement Using Six Sigma – A Case Study in Small Scale Industry, *International Journal of Six Sigma and Competitive Advantage*, Vol. 6 Nos 1/2, 2010, pp. 1-11.

APPENDIX 1

Figure 1. PT. LOL

Figure 2. Small Part for Motorcycle Battery

Figure 2. Small Part for Car Battery

Figure 3. Unfilled Defect

Figure 4. Shrinkage Defect

Figure 5. Casting Process

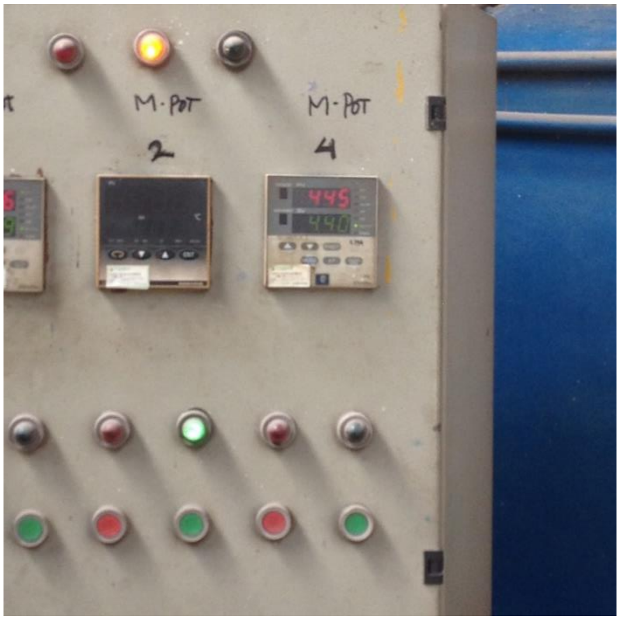


Figure 6. Collecting Data for Experimental Design

APPENDIX 2

Table 1. Detail calculation of UCL and LCL current condition

Time	Number of observation	Sample	Defect	Ui	Centerline	UCL	LCL
9:45	1	135	25	0.1852	0.213115	0.3323	0.0939
11:00	2	130	30	0.2308	0.213115	0.3346	0.0916
13:30	3	125	20	0.1600	0.213115	0.337	0.0892
14:45	4	135	35	0.2593	0.213115	0.3323	0.0939
16:00	5	130	25	0.1923	0.213115	0.3346	0.0916
17:45	6	140	30	0.2143	0.213115	0.3302	0.0961
20:00	7	150	35	0.2333	0.213115	0.3262	0.1
21:15	8	135	25	0.1852	0.213115	0.3323	0.0939
22:30	9	130	30	0.2308	0.213115	0.3346	0.0916
11:45	10	125	25	0.2000	0.213115	0.337	0.0892
01:00	11	130	30	0.2308	0.213115	0.3346	0.0916
02:15	12	125	25	0.2000	0.213115	0.337	0.0892
03:30	13	140	35	0.2500	0.213115	0.3302	0.0961
04:45	14	135	30	0.2222	0.213115	0.3323	0.0939
06:00	15	130	30	0.2308	0.213115	0.3346	0.0916
07:15	16	140	25	0.1786	0.213115	0.3302	0.0961
	Total	2135	455				

APPENDIX 3

25/09/2017 13:03:05

```
Welcome to Minitab, press F1 for help.
Executing from file: C:\Program Files (x86)\Minitab\Minitab
17\English\Macros\Startup.mac

 This Software was purchased for academic use only.
 Commercial use of the Software is prohibited.
```

General Linear Model: shrinkage versus Cool time; temperature

Factor Information

Factor	Type	Levels	Values
Cool time	Fixed	4	6; 7; 8; 9
temperature	Fixed	4	440; 445; 450; 455

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cool time	3	45848	15282.7	146.29	0.000
temperature	3	4254	1417.9	13.57	0.000
Cool time*temperature	9	2130	236.7	2.27	0.028
Error	64	6686	104.5		
Total	79	58918			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
10.2210	88.65%	85.99%	82.27%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	127.02	1.14	111.16	0.000	
Cool time					
6	32.27	1.98	16.31	0.000	1.50
7	13.73	1.98	6.93	0.000	1.50
8	-24.47	1.98	-12.37	0.000	1.50
temperature					
440	3.62	1.98	1.83	0.072	1.50
445	8.03	1.98	4.05	0.000	1.50
450	-11.63	1.98	-5.87	0.000	1.50
Cool time*temperature					
6 440	-7.73	3.43	-2.25	0.028	2.25
6 445	5.67	3.43	1.66	0.103	2.25

6 450	-2.07	3.43	-0.61	0.547	2.25
7 440	-1.18	3.43	-0.34	0.733	2.25
7 445	-2.97	3.43	-0.87	0.389	2.25
7 450	5.68	3.43	1.66	0.103	2.25
8 440	7.63	3.43	2.22	0.030	2.25
8 445	4.62	3.43	1.35	0.182	2.25
8 450	-9.53	3.43	-2.78	0.007	2.25

Regression Equation

```
shrinkage = 127.02 + 32.27 Cool time_6 + 13.73 Cool time_7 -
 24.47 Cool time_8
            + 3.62 temperature_440 + 8.03 temperature_445
            - 11.63 temperature_450 - 7.73 Cool time*temperature_6 440
            + 5.67 Cool time*temperature_6 445 -
 2.07 Cool time*temperature_6 450
            - 1.18 Cool time*temperature_7 440 -
 2.97 Cool time*temperature_7 445
            + 5.68 Cool time*temperature_7 450
+ 7.63 Cool time*temperature_8 440
            + 4.62 Cool time*temperature_8 445 -
 9.53 Cool time*temperature_8 450
            + 1.27 Cool time*temperature_9 440 -
 7.32 Cool time*temperature_9 445
            + 5.92 Cool time*temperature_9 450
```

Fits and Diagnostics for Unusual Observations

Obs	shrinkage	Fit	Resid	Std Resid	
5	174.00	155.20	18.80	2.06	R
26	123.00	145.80	-22.80	-2.49	R
64	187.00	163.40	23.60	2.58	R
65	140.00	163.40	-23.40	-2.56	R

R Large residual

Optimization Plot

Response Optimization: shrinkage

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
shrinkage	Minimum		81	161	1	1

Solution

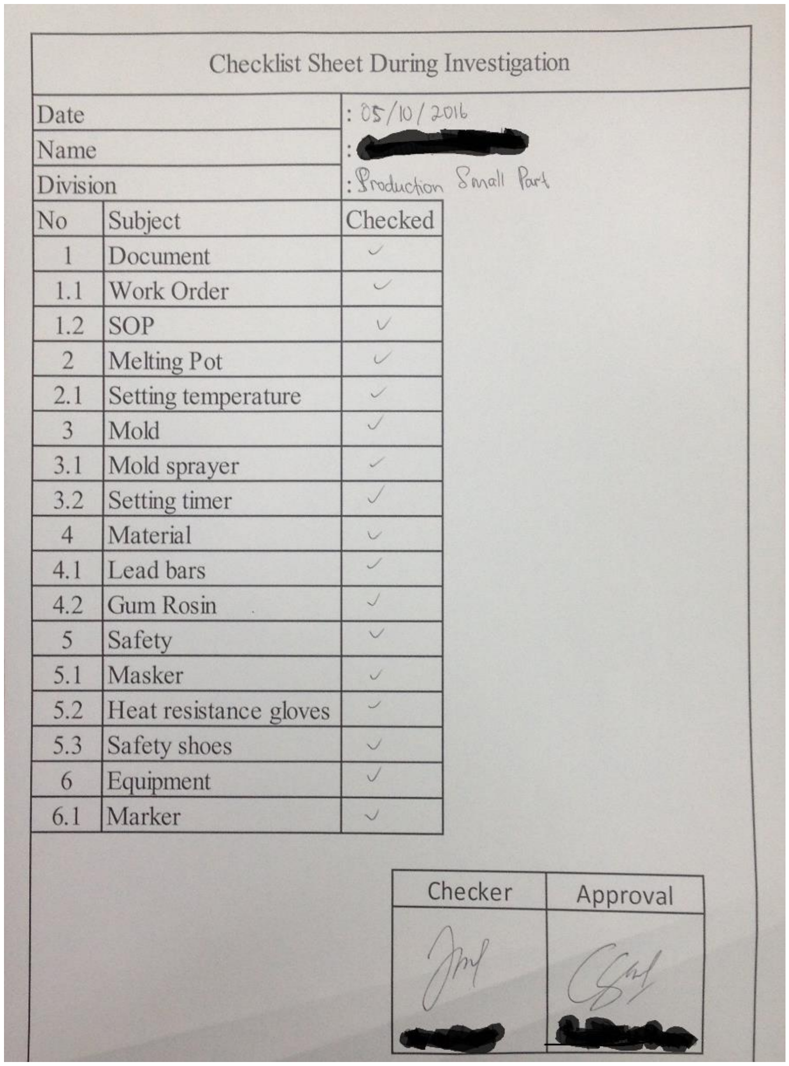
Solution	Cool time	temperature	shrinkage Fit	Composite Desirability
1	8	450	81.4	0.995

Multiple Response Prediction

Variable	Setting
Cool time	8
temperature	450

Response	Fit	SE Fit	95% CI	95% PI
shrinkage	81.40	4.57	(72.27; 90.53)	(59.03; 103.77)

APPENDIX 4



Checklist Sheet During Investigation

Date		: 05/10/2016
Name		: [redacted]
Division		: Production Small Part
No	Subject	Checked
1	Document	✓
1.1	Work Order	✓
1.2	SOP	✓
2	Melting Pot	✓
2.1	Setting temperature	✓
3	Mold	✓
3.1	Mold sprayer	✓
3.2	Setting timer	✓
4	Material	✓
4.1	Lead bars	✓
4.2	Gum Rosin	✓
5	Safety	✓
5.1	Masker	✓
5.2	Heat resistance gloves	✓
5.3	Safety shoes	✓
6	Equipment	✓
6.1	Marker	✓

Checker	Approval
[redacted]	[redacted]

Figure 7. Checklist sheet during investigation