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Preface

This thesis marks the finalization of the M.Sc. in Industrial Economic at the University at Stavanger. The work of this thesis was carried out at General Electric facilities in Stavanger. I would like to thank General Electric for earlier employment and for giving me the opportunity to write this thesis. As the last part of the period of my study, this thesis has been challenging and informative and I have gained a lot of new knowledge about both Six Sigma and Lean which I am certain will be beneficial in the future.

I would like to thank my supervision at GE, Deepa Ramanand, for excellent and essential guidance throughout the process and for taking time to share knowledge and discuss the thesis when needed.

My gratitude further extends to Eric Brun my supervision at the University at Stavanger. His advice and feedback throughout the process of this thesis has been much appreciated.

In addition I would like to thank every person that has been involved in this process. The contribution has been essential for the result of this thesis.

I also would like to thank my fellow friends and classmates for motivation, encouragement and coffee breaks throughout the years at INDØKS.

And finally, a very special thanks to my closest family for their support and advice throughout my master. It has been highly appreciated.

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Gitte Russøy Kalsvik

Abstract

Six Sigma and Lean are two of the most used improvement strategies in the world. In later years it has been argued that a combination of these will give an improved result compared to applying only one of the methods. The purpose of this thesis is to investigate the benefits and challenges of combining a Lean tool with a Six Sigma project. In order to study this in more detail a Six Sigma project was conducted using the steps of the DMAIC-model. The objective of the Six Sigma project was to reduce the cycle time in a maintenance process at a GE facility in Stavanger. During the project it was confirmed that some factors had an impact on the variation in the process and had to be addressed accordingly. These factors were either minimized or removed by utilizing the Fishbone from Six Sigma and the Value Stream Map from Lean. The result from applying these tools and the implemented measures that followed has resulted in a process that runs smoother and contains fewer defects. Another issue revealed was the way hours were being entered into SAP and a suggestion for how to improve this to make future work less time consuming is presented in the thesis. The result shows that the combination of these methods is feasible and has proven to be favorable for improving the maintenance process. The methods complement each other by focusing on different areas which in turn gives an overall improved result. More projects should however be conducted on different processes at different companies to check if such successful combination would repeat itself. Nevertheless, based on this thesis the combination is considered to be favorable.

imagination at work

Table of Contents

List of Figures

List of Tables

Acronyms

BBL	Black Belt Leader
BOM	Bill of Material
CC	Cost Center
CTQ	Critical to Quality
CTX	Critical to X
DC	Document Control
DFSS	Design for Six Sigma
DMADV	Define – Measure – Analyze – Design - Verify
DMAIC	Define – Measure – Analyze - Improve - Control
DPMO	Defects per Million Opportunities
E&P Drilling	Exploration & Production Drilling
FSO	Final Sign Off
Gauge R&R	Gauge Repeatability & Reproducibility
GE	General Electric
GRN	Global Rejection Report
ID	Identification
ITP	Inspection and Test Plan
LSL	Lower Specification limit
L1	Level 1
L2	Level 2
L3	Level 3
MA	Material Administration
NDT	Non Destructive Testing
OTD	On Time Deliver
OTR	Order To Remittance
PC	Project Control
PN	Part Number
QC	Quality Control
RTD	Rental Tool Department
SAP	Systems Applications and Products
SNR	Serial Number Record
SRTP	Subsea Rental Tool Planner
TC	Tool Coordinator
TIMWOOD	Transport, Inventory, Motion, Waiting, Over-production, Over-processing, Defects

TQM	Total Quality Management
USL	Upper Specification Limit
VOC	Voice of the customer
VSM	Value Stream Map
WBS	Work Breakdown Structure
WOP	Word Order Package
WS	Workshop

1.0 Introduction

1.1 Background

Over the last years the oil market has gone through drastical changes. Companies operating in this field have felt the consequences the low oil price brings. To ensure a sustainable company in such times modification and changes are essential to survive at this level of oil price. Most service companies are forced to restructure the organization and cut costs to ensure new contracts and secure future work. This means that they need to review and assess the execution of their work and projects and look at what changes and action that will be necessary to carry out to be profitable. There are several methods and approaches to improve performance and be more efficient and also reduce the cost in a company today.

The thesis is based on an internal process at a department at General Electric Oil & Gas (hereby referred as GE) in Dusavik. The department, Rental Tool, has a goal within 2016 to reduce the cost with 40 %. There are several processes they will be looking at to achieve this goal and one of them will be the maintenance process for the different tools in their fleet. This thesis will look at pros and cons relative to combining of two quality improvement methods for reducing cost which is conducted through a Six Sigma project.

The author has experience from the internal processes at GE through part-time position and an internship where the author was deputy for the Subsea Rental Tool Planner (SRTP). This has given valuable insight in the maintenance process and is also the motivation behind the thesis. Knowledge gained from earlier experience at GE and Six Sigma is integrated throughout the thesis.

1.2 Problem Description

The thesis addresses the application of Lean Tool in a Six Sigma process and how these tools can contribute to the final goal of the Six Sigma project. The problem of this thesis is approached by conducting a Six Sigma project for an internal maintenance process at GE where the goal is to reduce cycle time. As part of this project a Lean Tool has been utilized and the thesis has studied how the selected tool impacts the result of the Six Sigma project. Note that this is not the same as a Lean Six Sigma project; this will be discussed further in chapter 6.

Problem:

What are the benefits and challenges of combining Lean tools in a Six Sigma Project at General Electric?

This question is answered at the end of this thesis in the conclusion.

1.3 Scope of Work

This thesis approaches the benefits of combining Lean tools with the Six Sigma method by conducting a Six Sigma project on a maintenance process. A full size Six Sigma project is time-consuming and a high level of knowledge about the method is required. Therefore, due to time-limitation and the fact that this project is carried out by one person, and not a tem, the Six Sigma project is simplified and the guidelines for the project is carried out in close co-operation with the BBL.

There will not be sufficient time to look at all of the tools in GE fleet. A selection of the most frequently used tools and those with the highest cost relative to the 2016 goal were chosen. The data used for this thesis will be selected from the year 2015, since there was a change in the maintenance process at the end of year 2014.

1.4 Structure of Thesis

This thesis is divided into seven chapters and subchapters.

Chapter 1: Introduction, gives an introduction to the thesis and background as well as the problem to address, literature review, scope of work and the structure of the thesis.

Chapter 2: Theory, presents the theory around Six Sigma and describes in detail the process of how to perform a Six Sigma project, using the DMAIC model and the tools within this model. An introduction to Lean and the relevant tools are also presented.

Chapter 3: About General Electric, Introduction of GE and description of how the maintenance process functions.

Chapter 4: Method, describes the work process including what was done and the purpose why.

Chapter 5: Empiric, describes the execution and the results from the DMAIC-model. It Gives a summary of the Six Sigma project and describe the main findings of the thesis.

Chapter 6: Discussion, assess the findings in the previous chapters and discuss the results and the decisions that has been determined. Also, an assessment of the reliability and generalization of the data gathered is discussed.

Chapter 7: Conclusion, provides the conclusion of this thesis.

2.0 Theory

2.1 Six Sigma

Projects in Six Sigma usually start with the customer. The customer want products or services that are reliable, consist and predictable and this is what Six Sigma seeks to achieve; defect free business performance. The definition of a "defect" is any process output that does not meet the customers specifications. Six Sigma is a statistical term and measures how far something is from perfection [1]. Sigma, σ, origins from the Greek alphabet and is used by statistician to measure variation in processes referred as the standard deviation. The performance of the company is measured by the sigma level they have achieved. A Six Sigma level means that no more than 3.4 defects per million opportunities (DPMO) can be delivered in the long run as showed in Table 1 below.

Table 1: The Sigma Scale [2].

Sigma Level	DPMO	Yield
6	3,4	99,9997 %
5	233	99,977 %
4	6 210	99,379 %
3	66 807	93,32 %
2	308 537	69,2 %
1	690 000	31 %

The average companies will accepted a three or four sigma level, however such a level will produced between 6 210 to 66 807 defects per million opportunities. Even though a company never reached Six Sigma, there are still massive savings opportunities if the company manages to climb from one level to a higher [1].

The general equation Six Sigma is based on is [3];

$$Y = f(X) + \varepsilon$$

- *Y is the wanted result*
- *X represents the different factors that are needed to create the outcome. There can be numerous factors*
- *f is the function where the factors are transformed into the wanted result*
- *ε , Epsilon from the Greek alphabet, represent the variation in the process and is the uncertainty with the different Xs and their transformation into the result*

This equation is often called the breakthrough equation, and to be able to control the outcome an understanding of the root causes, the Xs, is necessary.

To improve quality it is necessary to reduce the amount of defects per million opportunities (DPM). There are two attributes to this metric that can be controlled [1].

- Opportunities: reducing the number of steps, hands-off and other "opportunities" that will improve quality.
- Defects: reducing the number of defects in the process through continuous process improvement and control will increase the quality-level.

Both of these will be applied in this thesis to improve quality.

2.1.1 The Technical Perspective

Six Sigma often referees to important factors as Critical to Xs (CTXs) and the Xs represent different characteristics like time, cost and quality to mention some (ref six sigma handbook). Take an example of a screw that is manufactured to be assembled with other components and it is crucial that the length of the screw is 20 mm long, yet a variation limit at + - 0,001 mm is acceptable. Every screw that is made within these specifications are approved, screws that do not have the desired length will be defined as a defect. The length of the screw would be defined as CTQ – Critical to Quality; if the screws do not have the right length the screw is not usable for further work. In other words, variation is deviation from the result expected and huge variation in a process will lead to poor quality which influences the costumer and their satisfaction.

Any cost that would not be expended if the quality was perfect is defined as cost of quality. Such cost can be obvious like for example rework, scrap, warranties, lost sales, but also less obvious expenses like defect materials, costs relative to shipment of replacements and the cost of the personnel to order the replacement. Poor quality impacts companies in two ways [2]:

- Higher cost
- Lower customer satisfaction

When you already have high cost relative to the poor quality, the domino-effect will be lower customer satisfaction and loyalty which will affect the revenue due to fewer sales. This result of poor quality can, if not dealt with in time, threaten the existent of the company. Hence this factor is important to keep track of to ensure that the cost of poor quality is within the commonly measured failure cost sat by the company

The most commonly used distribution in Six Sigma is the normal distribution showed in Figure 1 below. Companies usually have a distribution of performance around a target, which is also referred as the mean and will often give the shape of a bell. The values are centered round the mean and the curve is symmetrical on both sides. Processes often have one or two specifications limits, lower specification limit

(LSL) and upper specification limit (USL). Values below or above these limits will be defined as unacceptable. The closer the values are to the mean, which is the ideal value, the better process.

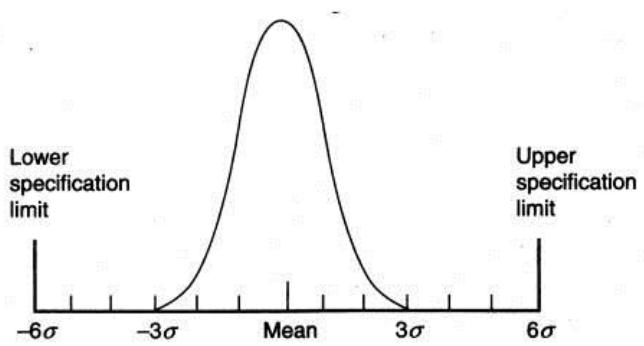


Figure 1: Normal Distribution [4]

A process with only one specification limit (lower or upper) will, when achieving Six Sigma, have six standards deviations from the mean and to the specification limit. If there a lower and an upper specification limit there will be six standards deviation at both sides of the mean.

In a three sigma process the values are widely spread along the mean line, which shows that at this level there are a higher number of variation and defects. Whereas at a six sigma level the values will be closer to the mean line, indicating that the process has less variation and defects.

In a process or organization there will always be errors and this is inevitable, but the extent of the variation will be possible to influence and also the type of variation. There are two different causes of variation; common and special cause. Some variations are natural and they cannot be eliminated. Like the height of trees in a forest, these will vary and it is a natural variation and the phenomena are constantly within the system. In the statistical world these variations are defined as common causes of variation. Events like a puncture tire or an operator that fall asleep are the other kind of variation, special cause. They are caused by a source of variation that is new, unanticipated and unpredictable and is not a part of the constant system. The common causes cannot be removed from the system and will always exist, whereas the special causes can and should be identified and eliminated from the system. In Six Sigma projects it is always these special causes of variation that are searched for and removed from the process.

A process will in the short-term stay within the specifications limits given when improved, but in the long-term the process will drift and shift due to common cause of variation. Therefore, over time the process bandwidth will increase and the chances for defects are more likely. This shift needs to be taken into consideration. A typical process will shift about 1,5 sigma [5]. This means that when a company claims to have 6 sigma, this may be correct for the short-term but in the long run the process will have an sigma level at 4,5 sigma.

Another important factor to be aware of when implementing new methods is the quality of the product or service that are delivered. Even though reduction in cost is necessary occasionally it is important that the savings will not impact the quality of the product/service or it will be necessary to come up with a new quality level that still satisfies the customer and is within the required specifications.

2.1.2 DMAIC: Define, Measure, Analyze, Improve, Control

Generally

The Six Sigma initiatives are closely related to Total Quality Management (TQM) and the complexity that characterize TQM [1]. Six Sigma use a handful of proven techniques and combine them with a small group of highly technical trained personnel, known as Black Belts, which carry out different projects with other staff members where the goal is to improve the process or organization. To become a black belt project leader several course and projects need to be done and approved [1,6]. The different belts in the Six Sigma belt hierarchy is showed below in Table 2.

Table 2: The different Belts in SS

Belts in Six Sigma	Explanation
Master Black Belt	The highest level of Six Sigma expertise
Black Belt	Full-time project leader
Green Belt	Part time, focused on different tools in SS
Yellow Belt	Awareness of SS-tools

Every Six Sigma projects follows either the model for already existing processes or ogranizations, DMAIC: Define-Measure-Analyze-Improve-Control or the model for new process or organizations, DMADV: Define-Measure-Analyze-Design-Verify. DMADV-model is also known as DFSS – Design for Six Sigma. DMADV is used to design and develop new processes or product and also for process that has been optimized but still do not met the customer specifications [6]. This thesis will focus on an already existing process at GE facility and therefore the DMAIC-model is selected.

The DMAIC-model is the core of Six Sigma and is a five-phase improvement cycle and every tool used is applied within this model. The different phases in the model are given in a brief overview in Table 3 below.

Table 3: DMAIC-model [7]

Six Sigma phase	Explanation
Define	Define the projects objectives, boundaries and choice a team
Measure	Measure the existing system to define the baseline
Analyze	Analyze the data and identify ways of eliminating the gap between the baseline and the goal of the project
Improve	Use tools to improve the process or organization
Control	Control the new system and establish plans and procedure to ensure that the changes are sustained

Before starting with any process improvement project, it is essential to choose the "right" project. There are many Six Sigma projects that have a poor start from the very beginning and some of the reasons are listed below [8]:

- The scope is to broad
- There are several goals
- The problem is to easy
- Already know the solution to the problem

To ensure to choose the right project close co-operation with the Master Black belt or Black belt is important since they have the competence and skill to assess if the project should be preceded or terminated at this stage.

DMAIC-Model

The theory from the different phases listed below is gathered from the book "The Six Sigma Handbook". The book clearly describes each phase in a way that appears to be fairly representative for the general theory behind the DMAIC phases. This is supported through the literature review where the studied articles define the phases similar to the book.

Define

The first phase in the DMAIC-model is to confirm that the process looked at is causing problems for the company and based on that define the project. It is necessary to ensure that everyone working in the team understands the scope of the project and has a clear picture of the process to be improved. Estimate of cost and timeline are important to establish to make sure that the project cost will not exceed the benefits gained. This phase should also define the "Y" to be improved, which is the result variable. Further, when the team has established that there are indications of a process issue, the problem statement must be created. The statement should include the severity of the problem, the impact of the business and the specific areas of departments that will be involved in the project. The *Define* phase should also include a process map or a detailed description of how the process works and a Gantt chart which illustrated the project schedule. The Voice Of the Customer (VOC) is the customer's expectations to the product or service. The VOC should be determined in this phase since Six Sigma is customer-driven and the need and demand of the customer should be addressed throughout the project. From the VOC the CTQ can be determined.

Measure

A measurement is a numerical assignment to an observation and is the second phase of the model. The goal is to gather as much information as possible about the process. It is necessary to measure the performance of the process to understand how and how well it works to figure out the gap between the current performance and the desired performance for the future. This is considered the most difficult and time-consuming phase of the DMAIC model due to selection of which Xs to further investigate. The collected data is the heart of the DMAIC model and if the data turn out to be useless or not valid the project will give little or none value at the end since the result is based upon faulty data. The importance of a valid data set cannot be stated enough. When the *Measure* phase is done the dataset should create a process capability baseline for the current performance.

The data collected is either discrete or continuous, and this is important to be aware of since this will influence which tests that should be chosen for further work. Data that has a finite number is called discrete, while data that exist on an interval is defined as continuous. Number of student in a class would be discrete, while the height of a person would be continuous.

The data that is collected is placed in a system which is often referred as measurement system. This system should be analyzed to ensure that it is reproducible, which means that the system need to produce the same result regardless of whom of the trained employees that uses it. To evaluate the measurement system a Gauge Repeatability and Reproducibility (Gauge R&R) is often conducted to see how accurate the measurement system is.

Analyze:

The object of the *Analyze* phase is to identify the root causes for variation of the process. This phase will also reveal the process capability which is the process ability to meet the specifications. It is the predictable performance that can be expected without doing any improvements of the process. During the *Measure* phase the team should have a clearer picture of the situation and give some indications on which steps that are contributing to most delays, cost and quality problems to mention some. Accordingly, the identifying of the process factors, Xs, is necessary to see how they affect the process result, Y. The data is analyzed with different tools to evaluate how big impact they have on the result. Different charts e.g. Pareto chart combined with statistical tests using p-values are often used to describe the situation. It is also important to determine whether the data set is normal or non-normal and the result of the data will then determine which tests to use further in the hypothesis testing. Then the top 2-4 potential root causes are selected and the goal will be how to eliminate these. The *Analyze* phase main goal is to determine the few vital Xs, root causes, and to acquire as much knowledge as possible to decide how to improve them at the most efficient way.

Improve

Six Sigma is centered around improvement and the goal of this phase is to figure out how to eliminate the root causes found in the *Analyze* phase and propose a solution to the problem that the project aims to address. This is usually conducted through brainstorming potential solutions, decide upon the proper tools and utilize them and implement the solution. Also to involve the people who work on the process that is being improved is important, since they can contribute with valuable information and ideas to which improvements to implement. This will not only give a more accurate picture of the situation but the personnel taking participating will also gain new knowledge. When the solution is determine and implemented in the process another data collection will be necessary, like the one conducted in the *Measure* phase. The new data also need to go through the same tests as the first data set. The test will be compared and from these it will be possible to see if there has been any improvement and whether the Xs is minimized or removed from the process.

Control

The final phase of DMAIC is the *Control* phase and the main objective is to maintain the gains in the long run. In other words, a control plan needs to be developed and implemented to ensure that the personnel embrace the new solution and not fall back into old routines. The solutions need to be standardized, the procedure needs to be documented and the employees need to be trained and informed of the result of the project. A continuously plan for monitoring the process is necessary and how the personnel should react and solve potential problems that may arise. Also, a clarification on who that has the different responsibility and ownership for the different task in the new implementation plan needs to be sorted out.

DMAIC Tools

In Six Sigma there is no pre-defined sequence or set of tool that *must* be used in each phase. The selection of tools that are used for the different phases of DMAIC need to be based on logic, knowledge and the projects specific challenges [2]. The five phases in the DMAIC-model has several tools that can be used in each phase, a few of them are showed in Table 4. Most of these tools are specially developed for Six Sigma whereas one is collected from the Lean method. The tools listed in the table are the ones used for this thesis and will be explained in further detail.

Table 4: Six Sigma and Lean tools in different phases [1]

Project Phase	Six Sigma and Lean tools
Define	VOC Process map
Measure	Pareto chart Gauge R&R
Analyze	Brainstorming Process Performance and I and MR chart Hypothesis testing HOV-Levene`s test Moods median test Regression
Improve	Fishbone VSM
Control	Control Plan

VOC – Voice of Customer

This represents all the needs and expectations that the customers have to the product or service. It provides important feedback and requirements that should be taken into considerations throughout the DMAIC-model. There are two different requirement that often is separated when speaking about VOC is the "need" which is what is absolutely required from the customer and becomes the CTQ and then there are "wants" which can be something the customer would like to have. The reason for separating these is that the needs are important critical features while the wants are expectations beyond the needs.

The feedback is gathered through communication with the customer and there is three key VOC tools to use for this:

- Surveys
- Interviews
- Focus Group

They can all be combine or one or two can be used alone.

Process Map

A process map is a detailed map that visualized how the process is carried out. It contains of different symbols that represent different actions.

Pareto chart

The Pareto Chart is used to visualize the importance of the differences between data-groups. The chart contains of both bars and a graph line, and they are ordered from the highest to the lowest related to their criticality.

Gauge R&R

A Gauge repeatability and reproducibility test will analyze the measurement system and estimate the amount of variation inherent in that system. It is a way of resolving how well you are seeing the true value of whatever that is measured, just as an eye test determines how well you are seeing images or words. If the test is not acceptable an instruction guide of how the measurement system should be used would be required.

Brainstorming

Brainstorming is a process where new ideas and solutions take form, often as a group acitivity.

Process Performance and I and MR Chart

The Process Performance chart tell you how much of the process at current performance that will stay within the Lower and Upper Specification Limits set. The I-chart on top shows the process level and graphs the Individual (I) values of each measurement and the mean of these values while the Moving Range (MR) chart below displays the variation for each measurement in the process. The control limits in the I and MR chart are set automatically by Minitab so that only 1 in 1000 points will fall outside of these control limits. The purpose of this is to get a better visual display of the values and to assess whether the process is under control or not.

Hypothesis Testing (null)

The analysis of the root causes can perform with hypothesis testing. A hypothesis is a proposed explanation on an event, and these need to be tested to evaluate the credibility of the hypothesis. Hypothesis testing usually contains 4 main steps (ref the six sigma handbook):

- Formulate the hypothesis
- Collect data to test the hypothesis
- Calculating statistics based on the data collected
- And from the calculation you either reject or accept the hypothesis based on a predetermined acceptance criterion

HOV Levene`s test

Levene`s test is a statistical test used to determine if a two or more groups have equal variance. Meaning the test checks the spread of the inputs. If the result of the test is less than typically 0,05 the samples are unlikely to have equal variance and the hypothesis is rejected.

Moods median test

Mood`s median statistical test is a nonparametric test that tests the null hypothesis to determine whether the medians of two or more groups differ or are identical. Meaning the test checks the centering of the inputs with respect to the mean. If the result is lower than 0,05 then the hypothesis is rejected.

Regression

Regression is often conducted in the *Analyze* phase and the result of the regression will estimate the relationship between variable through a predicted equation from the regression analyses. The equation uses on or more variables to explain the variation in the process. Once the regression analysis has been successfully applied the predicted equation can be used to estimate the amount of variability in the process and also the uncertainty around the equation.

Fishbone

A team discusses and lists different variables in a shape of a fishbone that may influence the end-result.

Control plan

A plan that describes the work needed to be conducted and defines the area of responsibilities for the personnel to ensure that the benefits gained by the project are maintained.

2.2 Lean

The mindset behind lean can be drawn back to Henry Ford, that continued to focus and develop Frederick Winslow Taylor innovative thinking, when he increasing the efficiency in his production lines when producing the Ford Model T. In 1922 Ford described in his book "My Life and Work" the ineffective work of the farmers in USA. He was one of the first that truly understood how big of an impact the speed of a process had for the overall cost [2]. Still, it was the Japanese car manufacture Toyota that developed the philosophy behind Lean as we know it today. The process of Lean was described in detail by James P. Womack, Daniel Roos, and Daniel T. Jones in their book "**The machine that changed the world**" in 1990. It was the first book that revealed the Lean production system that was the core and the basis of Toyotas lasting success [9].

The aim of Lean is to make the waste in a production visible in order to remove it from the process. This will increase quality, improve cycle time and optimize the flow of products, services and information throughout the whole process. The Japanese defines 7 types of waste that decrease the speed and quality in a process [10].

- Overproduction
- Waiting
- Transport
- Over-processing
- Unnecessary inventory
- Unnecessary motion
- Defects

To remove and eliminate these types of waste Lean has a numerous tools that can be applied. The one that are used in this thesis is described in detail. A well known tool in Lean is the Value Stream Mapping. This tool looks at how value flows into and through a process and to the customer and highlight both value adding, non-value adding and necessary none-value adding and often a current state map is drawn. Value adding step are the activities the customer is actually willing to pay for like changing tire, while necessary non-value adding steps are for example the personnel that is unpacking the tires and both of these activities are necessary for the process. Whereas the non-value adding steps need to be removed from the process and can for example be waiting for the right tool before the tires can be changed, this is an activity the customer is not willing to pay for. At the end a flow chart for the future state process should be developed.

2.3 Lean Six Sigma

Lean Six Sigma builds upon the characteristics from both of the two well-known methods. The two methods focus on different improvements area, where Six Sigma focus on removing defects Lean focus on speed and time. The fusion between these two methods was said to be necessary by Michael L. George in his book "Lean Six Sigma: Combining Six Sigma with Lean Speed" [2], due to the fact that Lean could not have statistical control of any process and Six Sigma could not improve the speed of the process dramatically or reduce the invested capital. Combining these methods amplifies the strengths and minimizes the weakness of both approaches when used alone. Lean and Six Sigma improve the speed and quality of any process by eliminating eight kinds of waste:

- Time
- Inventory
- Motion
- Waiting
- Over production
- Over processing
- Defects

These types of waste are often referred as TIMWOOD and the 7 first is exactly the same as in the Lean methodology whereas "Defects" are added from Six Sigma. These are the activities in your company that do not add value to your product but add costs.

2.4 Literature Review

Six Sigma is an acknowledged methodology in the quality management world and was introduced by Motorola in 1987 [11]. The last decades it has become maybe one of the most notorious methodologies used and several companies explain their massive savings with implementation of Six Sigma like for example General Electric. Jack Welch which was the CEO of GE in 1995 made Six Sigma the core of his business strategy and from that day and forward the methodology has increased in popularity [12]. Despite of this there is some scepticism regarding the failure to deliver performance benefits of the methodology [13,14].

Compared to other quality management systems like Lean and Total Quality Management (TQM) there is performed little research on Six Sigma [14, 15-18]. A reason for this can be that there has not been established a clear definition of Six Sigma [11, 17]. The methodology has been defined differently in numerous articles and books but the uncertainty of one final definition leads to confusion [11, 12, 17]. Schroeder et. al. (2000, p. 2) [17] defined Six Sigma as an "organized and systematic method for strategic process improvement and new product development that relies on statistical methods and the scientific method to make dramatic reduction in defect rates as defined by the customer". In 2008 Schroeder et al. (2008, p. 5) [12] invented a new base-definition; "Six Sigma is an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives." Still, it emphasizes that one definition may not suit for every company. To ensure a base-definition that fit their company they should customize it to their specific situation [19].

Although Six Sigma builds upon already existing quality management approaches [17] which has led to several discussion upon the lack of new ideas and that six sigma is just a repackage of existing methodology [20], other concludes with Six Sigma to contributes with a new structural improvement methodology which encourages the companies with more investigation and control [14, 19, 21].

Six Sigma can show for decades with successfully implementation and massive savings at big companies like GE and Polaroid to mention some [11], however there is still some concern regarding the failure rate of implementing Six Sigma [22]. Companies have reported difficulties about the implementation, too expensive programs and lack of sufficient results [22]. Reasons for failure for some companies are lack of thorough examination of the economic consequences [23] and not fully understanding its principles, concept or tools [20]. There are also those that claim the reason for failures at some companies is the lack of an implementation model to follow [24]. There are several influencing factors to be aware of when implementing Six Sigma [20, 21, 25] Executive engagement from the top management is one of the most critical factors to ensure a good implementation [16], followed by understanding of the methodology, training, follow-up and linking Six Sigma to the customers [20]. Furthermore the project selection, goals and project success in the initial stage of the implementation is also important [20, 21]. The leaders must be aware of the importance of supporting and training the employees while using the methodology of Six Sigma. If not, the employees can easily get demoralized by the challenging improvement goals, which will lead to lower performance in general [6]. Furthermore, a succeeding project will bring benefits to the company in the short-run and this will motivate the practitioners to proceed with the implementation [21]. There is a common understanding that implementing a strategy successfully is difficult, time-consuming and dedication from all levels is necessary. A good understanding of change management would probably help regarding the understanding for how to motivate and implement the new strategy and methodology [26]. The new strategy need to become the employees way of thinking and doing business and strong leadership is required for manage this [11].

There is little doubt Six Sigma contribute to a lot of discussion in proportion to its originality and the benefits gained from the methodology, nevertheless the enormous savings that are reported from companies using Six Sigma cannot be ignored.

Lean and Six Sigma is today one of the most popular quality methods to enable continuous improvement in different sectors like manufacturing and services [27] and several state that a combination of these two methods can achieve better results than what either method could achieve alone [16, 28-32]. Some argue that the two methods are essentially the same thing [28] while others agrees that in both methods the focus is on the business need defined by the customer [30,33] while Lean focus on eliminating steps which gives no value Six Sigma concentrate on minimizing or removing the variation in any process[30,31]. A panel of experts on Lean and Six Sigma where chosen to discuss the comparison of the two methods [30] and most of the people asked agreed upon that Lean is a generally easier and more straightforward method than Six Sigma and can be operated without much training required. Whereas a Six Sigma project would need certificated and trained people to ensure a proper execution of projects. Also some of the members of the panels had the opinion that to successfully implement both methods it would be necessary to use Six Sigmas DMAIC model as a general framework for the project and then apply Lean tools. This approach was also supported by the BBL involved in this thesis. There was also a very clear agreement upon the fact that Lean will give quicker result than the Six Sigma method. But if one of the methods is implemented without the other there will be lack of tools and strategy hence the full potential will not be reached [29,30]). To ensure that that the selected project can enhance the process to its full potential a Lean Six Sigma project can be used. This combines the two methods and focus on both removal of variation and the speed of the process. Yet, there is no clear definition on a Lean Six Sigma project compared up against either a Six Sigma with Lean tools or a Lean project with Six Sigma tools [33,34]. The grey zone between combining different tools together with either Lean or Six Sigma methodology or to conducting a Lean Six Sigma project is very diffuse. Some argue that it should be a 50/50 focus on both methods to call it a Lean Six Sigma project, while other means that you have a Lean Six Sigma once you combine them, regardless of the weighting of them [32].

The majority of the articles read states that the combination of these method are favorable and will give better results than implementing only one of them. Yet, using only Lean or Six Sigma would still give improved result if implementing successfully than not implementing any.

3.0 Background Information About GE

3.1 About GE

General Electric, or GE, is an American multinational corporation operating in several sectors including technology, energy, industrial finance, aviation and healthcare to mention some of them. GE was founded in 1892 and is at the present time ranked as number 24 of the world's 500 largest companies by Fortune. With over 45,000 employees worldwide GE Oil & Gas is one of the largest divisions in GEs conglomerate. In Norway GE has several businesses but the largest one is also here the Oil & Gas division and one of the main offices is placed in Stavanger where there are approximately 450 employees. GE Oil & Gas Stavanger provides solutions, maintenance and repair of offshore and subsea equipment [35].

3.2 The Maintenance Process at GE Oil & Gas

The maintenance process in the Rental Tool Department (RTD) is a complex process with many departments and personnel involved. The description of the maintenance process and the responsibilities of the personnel will be described later in this section. The subsea tools are booked and rented out for different jobs and are subject to various loads, wear and time on the rig. Since the tools can be exposed for enormous amount of strain during the job the maintenance process is essential to ensure that the tools meet the operational requirements.

3.2.1 How the Process Works

The maintenance process can be described through the following 11 steps:

1. Customer demand subsea tools for an operation
2. The subsea tool planner coordinates the new demand
    a. Subsea tools come back from other customer
    b. The planner determine which level of maintenance each subsea tool should have
    c. The subsea tools will be categorized either as a subsea tool that are going out on a new operation or to storage
    d. The Tool Coordinator (TC) are notified about the new demand
3. The TC prepare a work package for the subsea tool
4. The subsea tool gets delivered on site.
5. Material Administration (MA) moves the subsea tool into the system
6. Workshop start the maintenance work on the subsea tool
7. A+ (third party service) will perform None Destructive Testing (NDT) on L3

8. Quality Control (QC) inspect the work
9. If there are any defects or imperfection there will be made a list of what actions that would be necessary before receiving Final Sign Off (FSO).
10. Tool is prepared for shipment or storage.
11. MA moves it out of the system

The process above is a regular process and what it should look like but there will always be situations which are not taking into consideration, e.g. spare parts that are delayed or damage on tool, and then counter actions will be necessary to ensure delivery as planned.

3.2.2 Customer

GE delivers subsea tools to companies like Shell and Statoil to rent, but the demand from these companies goes through another department, Exploration & Production Drilling (E&P Drilling), at GE before reaching RTD. This means that for the RTD the customer is internal. It is the E&P Drilling (hereby referred to as the customer) that communicates the demand and need from e.g. Statoil to RTD.

3.2.3 Subsea Rental Tool Planner (SRTP)

The SRTP is the one that will get the demand from E&P Drilling personnel and communicate this further to the rental tool department and the TC. The SRTP needs to have an overview over every tool in the fleet and which operation they are out on. The demands also need to be coordinated and the different tools need to be assigned for the different operations in the future, often as long as half a year in advance. When the tool is back loaded, the personnel on the offshore installation will send information of the loads the tools has been exposed for. From this information the planner then decides which level of maintenance the tools require. There are three different levels;

1. Unused (Level 1, L1)
2. Used (Level 2, L2)
3. Recertification (Level 3, L3)

Level 1, unused means that the tool has just been out on the offshore installation but not used for the job. Such a tool will get a light maintenance check to ensure that the tool has not been damaged during the transportation. This maintenance check is often performed in one day and is the less time-consuming level of maintenance to carry out.

Level 2 means that the tool has been used for the job and a thorough examination of the tool will be necessary to ensure further safety use. This level can only be applied if the tool has been exposed for less than 80 % of total capacity load. If the load has exceeded this it will be required to perform a Level 3 maintenance check.

Level 3, which is total recertification of the subsea tool, will be required every fifth year and if the tool is exposed for a certain amount of load. Recertification of the tool means that the whole tool is disassembled and all of the component are checked and replaced if needed. This is done to verify that the tools have the essential requirements in order for a new five-year period.

The planner set a maintenance level and delegates the different subsea tools to different TCs and informs them on the new demand, when it will arrive and when it will be shipped out for a new operation or booked to storage. Subsea tools booked to storage will not be prioritized when there are other subsea tools that need to be ready for operations.

3.2.4 Tool Coordinator (TC/OTR)

The TC is the person that has the main responsibility for the subsea tool during the maintenance process and follows it through the whole process from arriving until it is has the FSO, which means it is ready for new operation or to be stored. A Work Order Package (WOP) is made which contains all the essential tool information and required actions based on the maintenance level. A L1 will need less information and instructions of the maintenance than a L3 since a L1 have less maintenance steps. However, the setup for the WOP will be similar for them all. The WOP contains:

- Front-page with information about tool, maintenance level and work order
- Drawings of the subsea tool/Bill Of Materials – BOM
- Inspection and Test Plan (ITP)
- Maintenance document - M-document
- Serial Number Record (SNR) List / Quality Control (QC) Report
- NDT Reports (L3)
- Global Rejection Reports (GRN)
- Punch List

The front-page contains information about the tool, identification, work order, maintenance level, TC, Work Breakdown Structure (WBS) number, and other comments like if the tool is damaged the TC should be reported. The drawings and bill of material shows what type of subsea tool it is and every component in it. The ITP describes for each maintenance level which activities that should be carried out to ensure a proper inspection of the subsea tool. The M-document explains how to disassembly, what activity to execute and how to assembly it. There are three different M-documents for a tool, one for each maintenance level. Every component that are within a tool are listed in the SNR-list. If the maintenance level require NDT test, the certificate of the test need to be enclosed to verify that the tool has the required specifications in order. If there are any damage or rejection of parts it need to be reported and this is done through the GRN. The report contains usually photos of the damage and the severity of the problem and an engineer will decide either to scrap or repair the part. When all of the above activities are carried out the WOP will be inspected by another TC to ensure that every activity is carried out properly and if there are found any irregularities it will be made a Punch List with the activities that need to be carried out and approved before the tool will receive a FSO. This setup will be similar for every WOP, regardless of which maintenance level the tool have. But the amount of information in these will be different.

M-document is the biggest document and describes in detail how and in which order to disassemble the subsea tool and what maintenance the different parts will need before re-assembling the tool. The WOP is delivered to the workshop and the maintenance work starts when the tool arrives on-site. Throughout the maintenance process situations can arise which will need to be addressed by the TC, e.g. parts that need to be ordered or approval from engineers regarding the tool functionality, and these events are not always easy to predict. The main goal for the TC is to have everything ready for the tool and workshop personnel when the tool arrives to minimize waiting time for the personnel or the tool.

Every morning the TC, SRTP, chairman of the WS and the chairman of RTD have a meeting to go through new updates and information regarding the subsea tools in the process and if there are any new demands from the customer. They go through a list in SAP which shows every subsea tool that is in the maintenance process. After each meeting they agree upon which subsea tool to prioritize and work on in the Workshop that day.

3.2.5 Workshop (WS)

The manager for the workshop (WS) participate on the daily morning meeting to update the TC and to get new information about subsea tools coming in, if there are any urgent cases and which subsea tools that should be priorities. After the meeting the manager delegates the information and work too his personnel in the WS. The subsea tools are at present time delivered outside the WS at an area called F14, where they are collected and moved inside the workshop. They are washed and cleaned before the personnel in the WS starts the maintenance work. Before the subsea tools arrive the WOP has been delivered in the WS by the TC and the worker follows the M-doc in accordance with how to disassemble, perform maintenance, and re-assemble the tool.

3.2.6 Applus (A+)

A+ is a third party company that GE hires to execute the non-destructive-testing (NDT) on the subsea tools that need a L3. The NDT is performed to ensure that there are no weaknesses in the material caused by wear and tear.

3.2.7 Quality Control (QC)

Every critical part in each subsea tool is to be inspected by QC and the main goal of the QC is to perform the necessary checks and tests to ensure that the subsea tool has been through the inspections needed by both WS and QC.

3.2.8 Material Administration (MA)

When the subsea tool is back on site it needs to be marked and put into the systems. The MA provides for placing the subsea tool at the correct location in both SAP and in storage. They also need to ensure that the movements are done correctly and they have the responsibility to register every location change the tool undergoes in the system. When a subsea tool is ready for operation the MA will remove move it completely from the system until it comes back from the field.

4.0 Method

A method is a plan of action, series of steps or a procedure which is used to solve a problem or acquire knowledge. The agreement with GE was to look for improvements in a maintenance process at GE using the Six Sigma DMAIC model. In addition to the DMAIC model a Lean tool was going to be applied in order to increase the overall success for improving the maintenance process. The DMAIC model is applied in order to identify improvement areas in a maintenance process. Data collection will be an essential part for carrying out the Six Sigma project. It will be necessary to select which data to use and also assess the data uncertainty. Uncertain inputs will give uncertain outputs, and these challenges need to be addressed while carrying out the method. Once the project has been defined and the data has been selected and gathered the next step will be to analyze the data and to improve the process by applying Lean and Six Sigma tools. Lastly it is important to maintain which ever changes or measures that were implemented based on the method.

4.1 Define

As stated in the theory chapter first part of the DMAIC-model is to define the project. This was done in co-operation with a supervisor from GE. It was necessary to confirm that there was a problem in the maintenance process before the project could be started and accepted by the BBL. This was done through study the available data from the maintenance process. The tool used in the *Define* phase, Voice Of the Customer (VOC), requires a meeting with the customer in order to identify important factors for the customer. The information needed for the VOC was gathered through a focus group where three of the customers had the opportunity to meet up to discuss Critical To Quality (CTQ).

4.2 Measure

There are two types of data that can be collected, *quantitative* and *qualitative*. The quantitative data will provide numbers and figures while qualitative will give data which cannot be translated into numbers. Six Sigma is a type of method that depends on statistical data but it is also complemented by qualitative information through e.g. VOC and Fishbone figure. The combination of quantitative an and qualitative data is favorable to better cover the whole picture of the maintenance process.

The planning of which data to collect and how to collect them was based on the problem description for the Six Sigma project, i.e. to reduce the cycle time for the maintenance process. Based on this, the data that would be needed are all hours used on each project in the sample. These hours need to be collected and translated into cost to reveal the gap between current and future state and also to see how much improvement that is necessary.

The next step would be to get an overview of the fleet and the subsea tools it contains. Further it is necessary to decide upon the correct subsea tools to focus on. The tools had to be selected by frequency of operations and by how much the cost exceeded the goal for 2016. To help choose the correct tools a Pareto chart was used. Also a feasible sample size need to be determined based on needed data for further tests and the capacity of the author. When the data was sorted the projects total cost can be calculated. The collected data was further organized in a system to more easily see the cost of each project together. Such an overview is usually called the Measurement System according to Six Sigma terminology. The list gives an overview over the different projects regarding the actually cost and how far from the 2016 goal they were. A validation of the Measurement System was necessary and was executed through a Gauge R&R test in Excel. The test was conducted with three operators from the maintenance process which were instructed to use and read the data in the Measurement System to see if the result would be the same. The uncertainty of the selected data needs to be assessed with the BBL in order to decide whether to proceed with the project or not.

4.3 Analyze

The analysis of the raw data collected is a process where the data is evaluated using analytical and logical reasoning to further assess the data. The goal of the analysis is to gain useful information to support the decisions that must be taken at a later stage in the Six Sigma project. Based on the selected data a meeting with the BBL was necessary to discuss which factors (Xs) that was most likely to influence the variation in the process. The factors chosen needed to be tested to see if they actually had an impact on the maintenance process. After gathering the data and validating the Measurement System was done, an assessment of the possible Xs was necessary. These Xs that may affect the variation in the process are chosen in co-operation with the BBL, since the selection should be based on the data set, knowledge and experience from the maintenance process. In addition a Process Performance test was conducted to see how the maintenance process behaved without any check the feasibility of the target cost set by GE. The result will either confirm that the target cost is possible or that adjustment is necessary. The next step was to conduct several hypothesis tests to investigate which Xs (critical factors) that had a significant impact on the variation in the maintenance process. MiniTab was used to check if the data was normal or non-normal and a flow chart was used to decide which hypothesis tests to apply. The critical factors, Xs, were then run through the different tests to check which of the Xs that have an impact on the process.

4.4 Improve

When the critical Xs were confirmed the Lean and Six Sigma tools to improve the process could be determined. Based on the Xs and the knowledge and experience of the BBL it was discussed that Fishbone figure and VSM would be the most beneficial tools to use. This evaluation of proper tools needs to be carried out by people with experience and knowledge about the pros and cons. The selection is based on the problem to solve, personnel availability, degree of difficulty and the time needed to perform them. The Fishbone figure required a team of personnel and the selection of personnel was based upon past work experience of the author. To ensure that sufficient information was gathered a diverse team was selected. The team consisted of the SRTP, a TC, a WC representative and the Customer. The team was gathered in a meeting room where the author had made an empty Fishbone figure with only the end-result "Level of maintenance not carried out right" in place. The purpose is for the team to utter their beliefs of why the maintenance level is not carried out correctly. Also, a VSM was conducted to reduce non-adding steps e.g. waiting in the process to improve the cycle time from the maintenance process. The VSM was conducted following tools around on the site and look at the inventory in the WS

To check if the improvement measures have worked as intended a new sample with data would be necessary to collect. The suggestions from the improvement phase need to be implemented and tested in the maintenance process through several projects. The time frame before enough projects has been conducted will depend on how many demands the RTD receives. In addition it is necessary to have a sufficient number of projects from each maintenance level. Due to natural work flow at GE the amount of projects required to do the final stage of the improvement phase is not available within the time frame of this thesis. Therefore the final phases need to be based upon two hypothetical datasets. To investigate if there had been improvements in the maintenance process, new samples would be necessary to collect. Both datasets will go through the exact same tests as the first sample, HOV Levenes, Moods Median and Regression test. The result will show either success or not success, and for the dataset that shows success a control plan will be necessary to sustain the benefits gained. If not success, a suggestion to go back and verify all steps to eliminate risk of incorrect data would be proposed. If nothing is found, the process may need a DMADV to improve at all, but the consequences, like time and cost, of initiating a new project needs to be evaluated.

4.5 Control

The purpose of the Control phase is to make sure that the gained benefits form the Improve phase is obtained for a long while after closing the project. Assuming success and initiate a control plan to make sure that the implemented measures are not abandoned when the project is complete. It is necessary to delegate tasks and responsibility to involved personnel and this is described in the control plan. The plan sums up how to maintain the gained benefits of the Six Sigma project and thereby control it. It is suggested to implement quality checks to verify that the implemented measures are being followed as described.

5.0 Empiric

5.1 DMAIC: Execution and Results

The execution of the five phases, *Define, Measure, Analyze, Improve* and *Control* has been chronological followed and the result is described in this chapter.

5.1.1 Define

The identification of the problem was done through a data analysis where the cost for 2015 was compared to the desired cost level in 2016 set by GE, as showed in Figure 2 below.

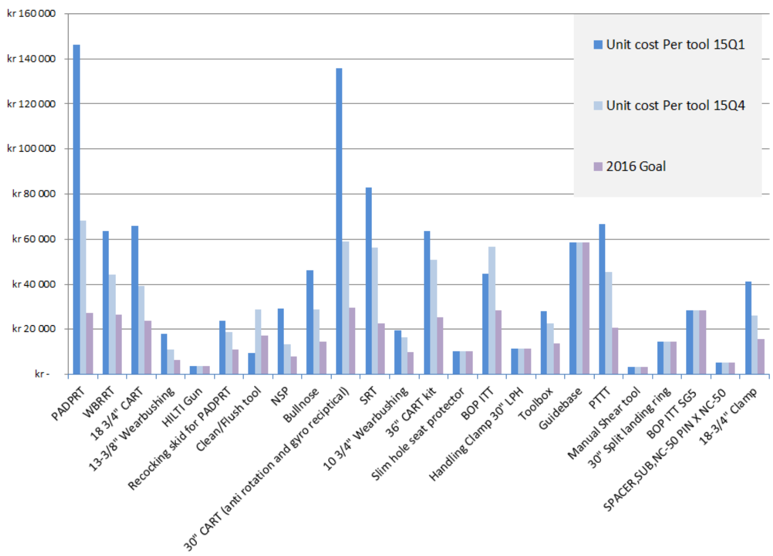


Figure 2: Cost of 2015 compared to the cost goal of 2016

As the figure shows there have been improvements throughout 2015 but there is still a great difference between todays performance and where GE want to be during year 2016. Based on the data above the project was accepted by the BBL. The scope of work was defined together with the BBL to ensure that the project would not become too demanding considering the timeframe and knowledge of the author. The timeline for the thesis was developed in a Gant-diagram to become more time efficient (see attachment 1). Usually a cost estimate is necessary to ensure the cost of the project does not exceed the benefits gained, but since this is voluntary thesis work, such estimate is not necessary.

The Problem Statement:

The maintenance process at the Rental Tool department at GE has in general over the last years experienced a too long cycle time. Due to the variation in the maintenance process only 11 % of the sample of 45 projects is within the goal for 2016. The extended cycle time increases cost and can also affect customer satisfaction due to undesired delays.

Severity of Problem:

The variation in the maintenance process is found to be significant and influences the end result. This can affect customer satisfaction and loyalty which further results in lower sales and revenue for GE. The main departments involved in the maintenance process are:

- Rental tool (RTD)
- E&P Drilling
- Workshop (WS)

Within these departments all of the Cost Centers (CC) mentioned in the *Measure* phase later in this chapter are found. The above departments use most of the hours registered, whereas the remaining hours are from departments involved only in special cases, like if a tool needs welding. However, this is considered to be extraordinary cases which are not found to be representative for the general maintenance process at GE.

Voice Of the Customer (VOC)

The customers gathered for the VOC got one main question that was; what are the most important factors for you when ordering subsea tools? The group discussion provided two absolute requirements; (1) the tool needs to be ready and have received a FSO and (2) be available in SAP for the customer at the agreed date. Based on this the CTQs was established to be On Time Delivery (OTD) and availability in SAP. The discussion also revealed several other "wants" like enhanced knowledge about the subsea tools among the involved personnel and implementing Condition Based Maintenance. However these are not consider critical to the cycle time of the maintenance process.

5.1.2 Measure

At GE the cycle time is defined as *all hours used on a subsea tool* and these are the data that needs to be collected. Such a collection of data would reveal the gap between current state and the future goal GE has for 2016. To visualize this difference the data need to be assessed relative to cost. In addition, the data gathered need to be from year 2015 due to a change in the maintenance process this year. Projects conducted before this year will not be representative for the maintenance process as it is today.

At GE the personnel enter their hours in SAP with a WBS number. For the RTD the main WBS is 909700 and this number refers to the department. The personnel in RTD need to use this reference when reporting the hours together with tool ID and CC. If personnel from the WS used two hours on a PADPRT that has the ID: NOR-R-1167, this ID needs to be entered as well. The WBS number would then be 909700-NOR-R-1167.The employees in the WS must also enter either 1050220 or 1050230 to identify the CC to where the cost is to be placed as these CCs are unique for the WS. The row marked with yellow in Figure 3 tells us that the personnel have worked in the WS in RTD and used two hours maintaining PADPRT NOR-R-1167. The employees do not always register the hours on the same day as the work is conducted and this means that hours could be lost or added to wrong projects when collecting data. The projects often start with the TC making the WOP, so in theory each project should start with hours entered by the TC and followed by the other CCs. The last entry is usually done by the DC which archives the WOP and should therefore be the last person to add hours on a project showed in Figure 3 above the green marked rows. To separate projects is easy if the tool has not been used for a while since it will be simple to conclude that hours registered one month after the end-date on the WOP belongs to the same project if the next project does not start before 4 months later. The problem arrives if the tools have been turn-around quickly and been through a maintenance check right after it came back after a short stay at the offshore facilitation. In such case the separation of hours is almost impossible to get right which compromises the reliability of the hours and data collected from SAP.

WBS: 909700-NOR-R-1167

Description	Date	CC	ID	Hours
TC	23.11.2015	1050117	909700-NOR-R-1167	0,50
WS	23.11.2015	1050220	909700-NOR-R-1167	5,75
WS	23.11.2015	1050230	909700-NOR-R-1167	7,50
QC	24.11.2015	1050212	909700-NOR-R-1167	5,00
TC	24.11.2015	1050117	909700-NOR-R-1167	1,50
WS	24.11.2015	1050230	909700-NOR-R-1167	4,50
WS	24.11.2015	1050230	909700-NOR-R-1167	2,00
QC	25.11.2015	1050212	909700-NOR-R-1167	3,00
WS	27.11.2015	1050220	909700-NOR-R-1167	1,00
TC	30.11.2015	1050117	909700-NOR-R-1167	1,00
MA	30.11.2015	1050300	909700-NOR-R-1167	1,00
DC	30.11.2015	1050213	909700-NOR-R-1167	2,00
TC	05.12.2015	1050117	909700-NOR-R-1167	1,00
TC	05.12.2015	1050117	909700-NOR-R-1167	1,50

Figure 3: Current SAP structure

The current structure in SAP at GE allows you to sort the hours relative to the different tools in the fleet. So, if the PADPRT NOR-R-1167 has been through only one maintenance check, all hours used on this project will lay under the WBS: 909700-NOR-R-1167. If the tool goes through another project, i.e. a new maintenance check, the hours used on this project will also be collected under the same WBS number. Consequently, every project the tool goes through will be collected in the same WBS number and cannot be separated using filters. This means that every project and all hours used on the PADPRT are gathered under WBS 909700-NOR-R-1167 and there is not possible to sort the hours by projects. This can be showed in Figure 3 above were the two last rows marked with green in the figure is actually the start of another project. The hours from this new project will also be enter at the WBS 909700-NOR-R-1167 together with all previous hours entered in SAP. As a result the hours used in a project need to be manually sorted out from this list. This means that separating the different projects can be quite difficult since the start and end date of the WOP not always agrees with the dates the hours are registered in SAP.

To collect the hours of the different subsea tools, every hour that is registered upon the main WBS 909700 need to be collected and extracted from SAP into an Excel sheet. Once collected in Excel the hours become more readily available for further processing with respect to cost and the list can be filtered by the tools that are focused on. To manage to collect the hours the physical WOP had to be available and at GE there is a small archive where the WOPs are stored for a while before shipped to the main storage at Tananger. Because of this only projects were the WOP was still stored in the archive at GE were selected. The hours and dates in the Excel list had to be compared to the physical WOP that followed the tool in the WS to identify start- and end-date and compare them with the data collected in the Excel sheet.

The hours are registered on CC which tells where the cost should be charged for accounting purposes. The different CC showed in Table 5 below has different payments by hour. When all hours for a project was collected a sorting regarding the different CC was necessary to be able to calculated and determine how much each project costs the RTD.

Table 5: Different Cost Centers

Description	Cost Center number
TC (Tool Coordinator)	1050117/1050211
QC (Quality Control)	1050212
WS (Workshop)	1050220/1050230
MA (Material Administration)	1050300
WS Apprentice	1050520
Document Control	1050213
Engineering	1020860
Sourcing	1010310
Welding	1050240
Field Service operator	1050510

Some of the projects gathered were conducted during summer 2015, and these hours are easier for the author to have control of since the author then worked as deputy for the SRTP following up the TC and tools. The author has knowledge about each project conducted during this period of time and therefore there are less uncertainty about these hours. The other projects are obviously more uncertain but the author has tracked every hour and talked with both SRTP and the responsible TCs regarding any irregular activities or hours that do not seem to belong to any projects. Regardless, there will not be a 100 % certainty that these hours actually are correct since only a few of the personnel the author has been in contact with update the hour list daily. This means that there can be uncertainty in the data collected in Chapter 4. However, the BBL and the author has discussed the uncertainties of the collected data and deemed them reliable enough to proceed the work.

Further, GE recommends having a sample size above 30 for a successful execution. However, in order to test several factors in the *Analyze* phase it would be necessary with a larger sample size that contained every tool with different maintenance levels and TCs. Therefore, it was decided to gather a sample size existing of approximately 40-50 projects if enough available WOPs in the archive. Due to large amount of work of data collection relative to the different tool types it was decided to focus on five different tools.

A Pareto chat was applied to determine which tools in the Subsea fleet to focus on. The Pareto chart was made by taking every tool and plotting the cost difference between actual cost in 2015 and the desired cost level in 2016. The red dotted line shows how frequent the tools were used for operation in 2015. As showed in Figure 4, the five tools marked with red have both high frequency of operations and a high cost relative to the 2016 goal. Consequently, these five tools types were selected for further investigation.

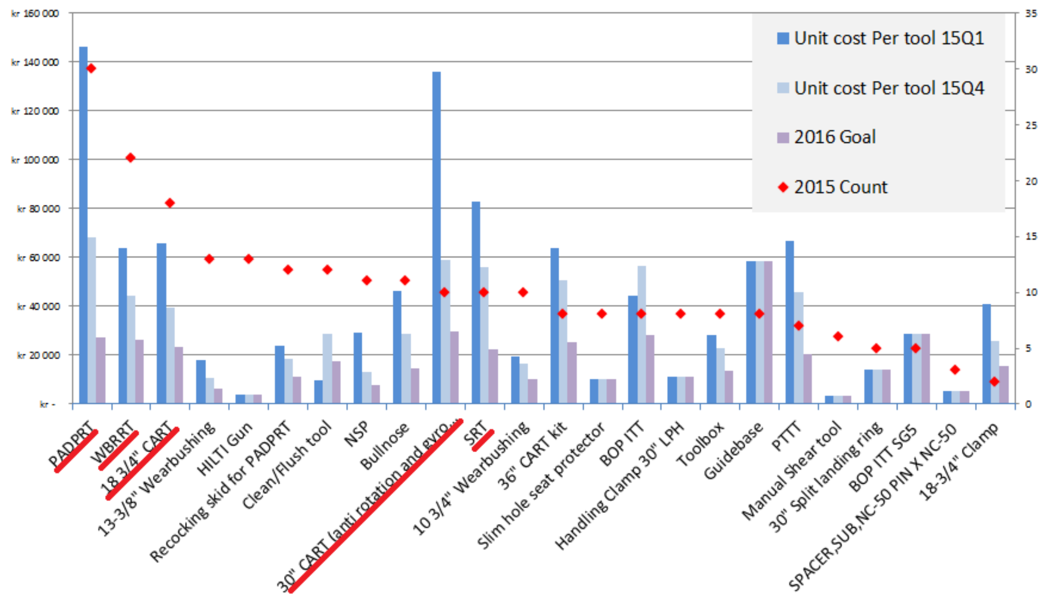


Figure 4: Pareto diagram for all subsea tools. Selected tools are marked with red.

There were 45 available WOPs with the right requirements in GEs archive. The hours collected for each of the 45 projects from the Excel file were separated by projects in a new file. To be able to calculate the cost for each project the hours needed to be sorted relative to the CC and then multiplied with the hour rate which then would give the total cost of the projects. The cost for each project was then compared to the goal for 2016 and the difference is showed in Figure 5 below.

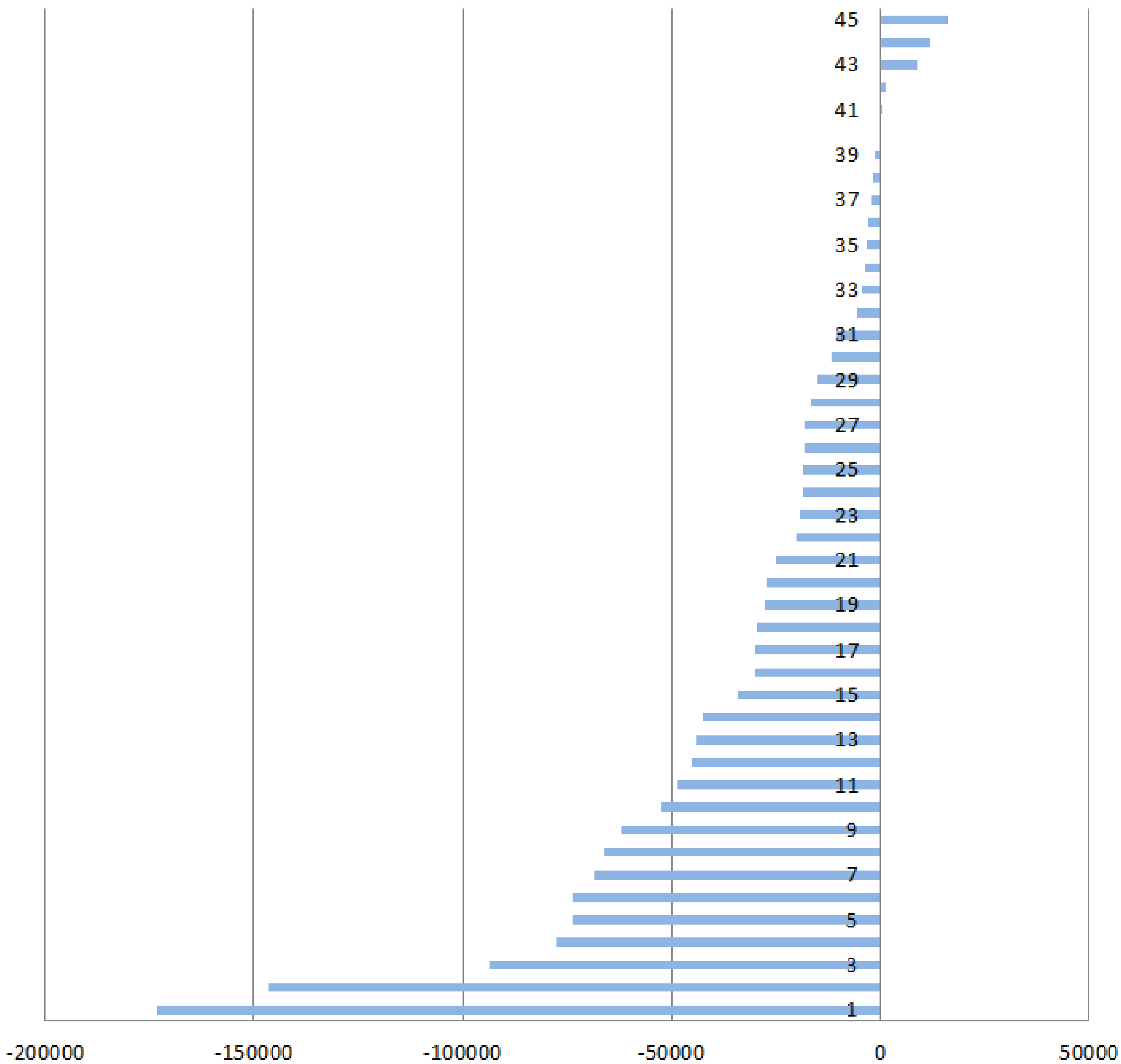


Figure 5: Difference relative to the projects conducted in 2015 and the cost goal in 2016

This result gave the baseline for the maintenance process and clearly shows that it is necessary with action if the goal of 2016 is to be reached. Out of the 45 projects only five were equal to or below the target cost for 2016. As Figure 5 clearly illustrates the cost of the 40 other projects vary from small offsets to significant deviation with respect to the goal for 2016.

The Measurement System showed in Table 6 needed to be assessed and verified through a Gauge R&R. One of the operators was asked to write down 10 tools from the list and their costs. Then he was set to explain to the two other operators which one he had chosen from the list. The two other operators then picked the tools and cost they thought was correct from the information given.

Table 6: A part of the Measurement System in Excel from the collected data (showing just some of the column due to sensitive information from GE)

Tool	P/N	ID	Level of Maint.	TC	D.T.W	D.D.	Diff.
PADPRT	H56570-6	BRZ-468	L1	TA	20.07.2015	18.08.2015	-1774,5
PADPRT	H56570-2	NOR-R-1164	L1	DL	30.10.2015	06.11.2015	1493,8
18 3/4 CART	H56018-1	R-0734	L1	AB	06.10.2015	19.10.2015	444,2

The test showed that the operators read and understood the system differently which can be seen by the different numbers in column “OPER1” and “OPER2” in Figure 6. A Gauge R&R result less than 10 % is acceptable, between 10-30 % may be acceptable while everything above 30 % indicates that there are issues that need to be solved. The result of the test gave an percentage of 601,01, which indicate that the Measurement System is not accurate enough and need modifications.

Part #	Part ID	OPER1	OPER2	OPER3	OPER4	OPER5	Range
		Measurement : BB Project Cycle Time					
1	Sample 1	7888,3	51004,3				43 116,000
2	Sample 2	51300,2	51300,2				0,000
3	Sample 3	17476	4263,2				13 212,800
4	Sample 4	62694,2	62694,2				0,000
5	Sample 5	66252,05	66252,05				0,000
6	Sample 6	7237,7	7237,7				0,000
7	Sample 7	17476	17476				0,000
8	Sample 8	4263,2	4263,2				0,000
9	Sample 9	51004,3	51004,3				0,000
10	Sample 10	7237,7	7237,7				0,000
						Sum of Ranges:	56328,800
						Average Range:	5632,8800

# oper	2
# parts (n)	10
d2*	1,16
LSL	0
USL	4161
Tolerance	4161,000

GAGE R&R	
Sm (Est.)	4855,93103
Gage Error (GRR=5.15*Sm)	25008,04483
%R&R = 100*(R&R/tolerance)	
%R&R =	**601,01 %**

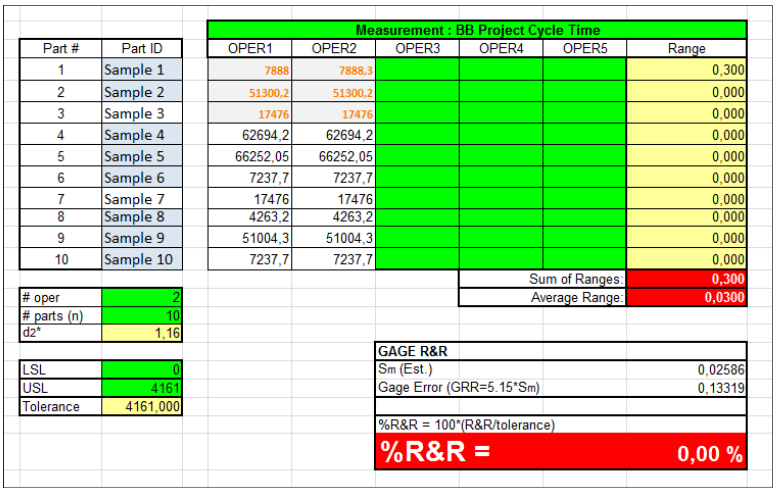
Figure 6: Gauge R&R to validate the Measurement System

To enhance the Gauge R&R percentage for the Measurement System an instruction on how to read the data was necessary. This would ensure that the operators asked for or described the required information to find the correct data in the system. The instructions were based on the authors knowledge about what information that would be required. As showed in Table 7 below there are several factors that need to be asked for or described to ensure picking the right tool and thereby also the correct cost. If one of these steps is forgotten there is a possibility of choosing the incorrect tool and cost. For example there are several PADPRTs that go through the maintenance process at the same time with same maintenance level, and if the operators do not ask for the ID of the tool they could select the wrong PADPRT. How to use and read the system is described in Table 7 below.

Table 7: Instruction sheet for the measurement system

How to use and read the Measurement System	
	Need to describe/ask for
Step 1	Which PN number does the tool have?
Step 2	What identification number does it have?
Step 3	Which maintenance level did it have?
Step 4	What are the start- and end-dates?

A new Gauge R&R was conducted together with the instruction sheet to ensure that the operators were selecting the right data from the Measurement System. The test was conducted in the same way as the first Gauge R&R. The result showed that the instruction sheet improved the measurement system significant and no deviation in was found in the system as showed in Figure 7 and therefore the Measurement System was accepted. When the Measurement System was accepted by the Gauge R&R test the next phase was to analyze the data gathered in the *Measure* phase.



Part #	Part ID	OPER1	OPER2	OPER3	OPER4	OPER5	Range
		Measurement : BB Project Cycle Time					
1	Sample 1	7888	7888,3				0,300
2	Sample 2	51300,2	51300,2				0,000
3	Sample 3	17476	17476				0,000
4	Sample 4	62694,2	62694,2				0,000
5	Sample 5	66252,05	66252,05				0,000
6	Sample 6	7237,7	7237,7				0,000
7	Sample 7	17476	17476				0,000
8	Sample 8	4263,2	4263,2				0,000
9	Sample 9	51004,3	51004,3				0,000
10	Sample 10	7237,7	7237,7				0,000
					Sum of Ranges:		0,300
					Average Range:		0,0300

# oper	2
# parts (n)	10
d2*	1,16
LSL	0
USL	4161
Tolerance	4161,000

GAGE R&R	
Sm (Est.)	0,02586
Gage Error (GRR=5.15*Sm)	0,13319
%R&R = 100*(R&R/tolerance)	
%R&R =	0,00 %

Figure 7: Gauge R&R improved Measurement System

5.1.3 Analyze

From the data collected some factors were found to be more likely to influence the variation in the process than others. The decision of which factors to investigate further was also supported by the work experience of the BBL and the author. The different Xs to investigate are showed in Table 8:

Table 8: Selected Xs to investigate

Xs	Description
x1	TC
X2	Type of tool
x3	Level of maintenance
x4	Cycle time

Managers wanted to have a target cost for refurbish and maintain the tools at 4100 kr. To see if this would be possible to accomplish it was conducted a Process Performance test in MiniTab. The Lower and Upper Specification Limit (marked in red) cover a very small area of the distribution as showed in Figure 8. This Process Performance estimates DPMO to be approximately 985 979 (showed in attachment 2). To manage to get the cost in between these limits would most likely be very difficult.

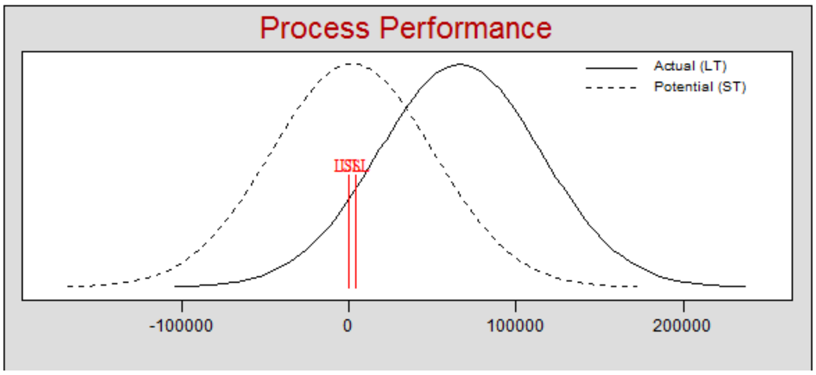


Figure 8: Process Performance for maximum cost 4100 kr

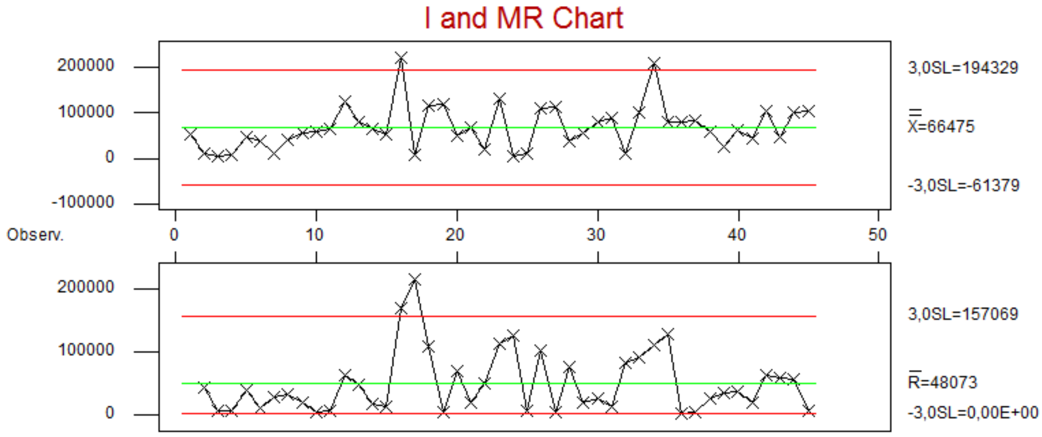


Figure 9: Process capability for actual cost – I and MR chart

The test in MiniTab also produced I and MR chart showed in Figure 9. The MR chart is the first to assess since this will tell if the process variation is under control. In the MR chart above several points are outside the control limits (marked in red) which demonstrates that this process is not under control. The I and MR chart indicates that the process average and variation is unstable and the maintenance process is not under control. Both the Process Performance and the I and MR chart showed that the maintenance process was unstable and based on this the goal of a target cost at 4100 kr would be difficult to reach.

To investigate if there were other possible target costs that would be more feasible the sample of 45 projects was put into a diagram that was split into the different maintenance levels at the X axis and the cost on the Y axis. This showed that project costs varied with the maintenance level and based on this it was suggested to have a target cost for each maintenance level.

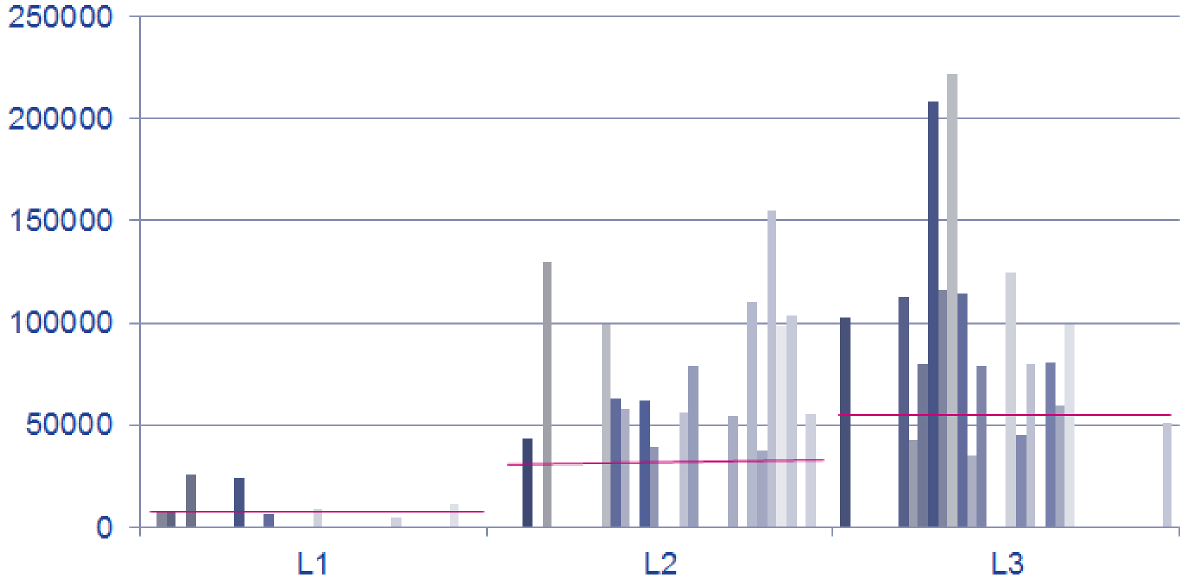


Figure 10: New target costs

The three different target costs were determined based on the average cost from L1, L2 and L3.

- L1 = 4161
- L2 = 31500
- L3 = 56000

The suggested target costs for the maintenance levels was proposed for the managers with the graphs and tests result from the I-MR chart to support the use of three targets costs instead of just one. It was decided by the managers to continue with these three targets costs, one for each maintenance level.

With the new target costs in place new process capability tests were needed. These tests were conducted in the same way as the first one, but with updated cost targets for L1, L2 and L3 (see attachment 3-5). All of the three new targets showed improvements in the Process Performance tests regarding how much of the curve that is within the LSL and USL. Also the DPMO decreased for all of the three new target costs. Figure 11 shows the new target cost for L3 is 56000 which clearly visualizes that the normal distribution fits better within these limits.

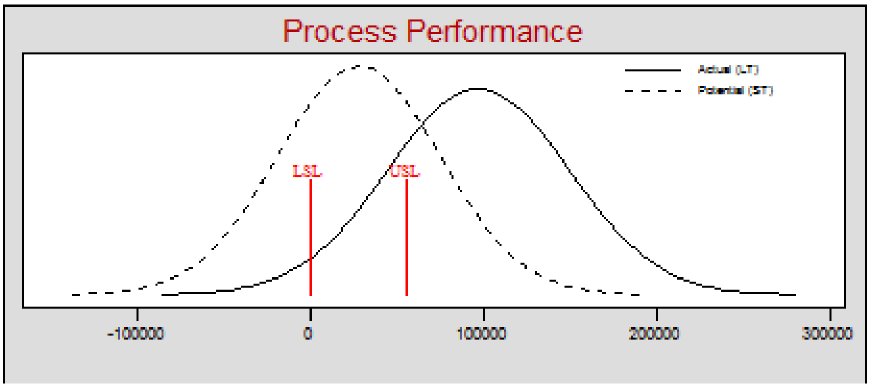


Figure 11: Process Performance for L3 with target cost 56 000 kr

The I and MR chart (see attachment 5) also showed improvements, however the process is still unstable. The result from the new Process Performance tests shows the state of the process at current time without doing any measures. Consequently, improvements are required to manage to reach the 2016 goal.

To determine whether the data collected was normal or non-normal a normality of the cost test showed in Figure 12 was conducted and gave a P-value of 0.028 as result and everything below 0.05 is considered to be a non-normal data set.

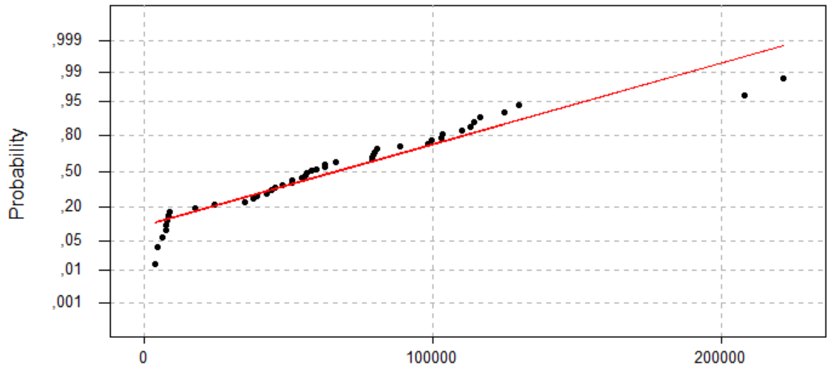


Figure 12: Normality of cost

For this thesis the Y is continuous, the three first Xs are discrete and the data is non-normal which leads to “HOV Levene`s” test for variation and “Mood`s Median” for centering as showed in Figure 13. Centering has originally three different sub tests that can be used relative to the different types of data, while “Mood`s Median” compares the median of two or more populations and would be the most beneficial to use. For X_4, this is a continuous X and therefore it should be tested with either correlation or regression, based on the flowchart. For this instance regression was chosen due to more knowledge about this test.

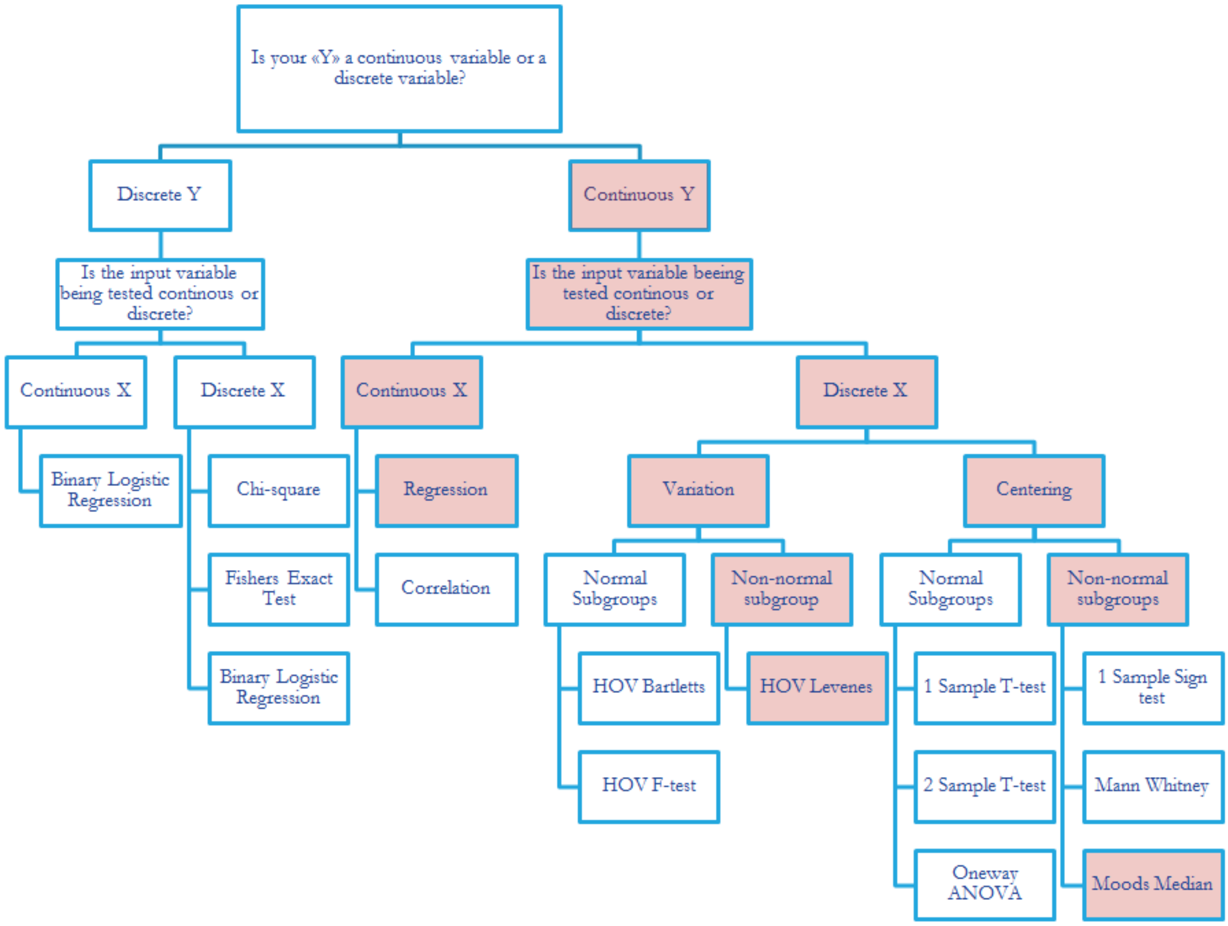


Figure 13: Flow chart to identify variation Source [3]

The first hypothesis was to check if the "type of subsea tool" was significant to the variation and centering issues of the data set. "HOV Levene`s" test has a H_0 and a H_a where the H_0 will be rejected if the P-value is below 0,05.

H_0: The different types of subsea tools have the same amount of variance

H_a: The different types of subsea tools have a different amount of variance

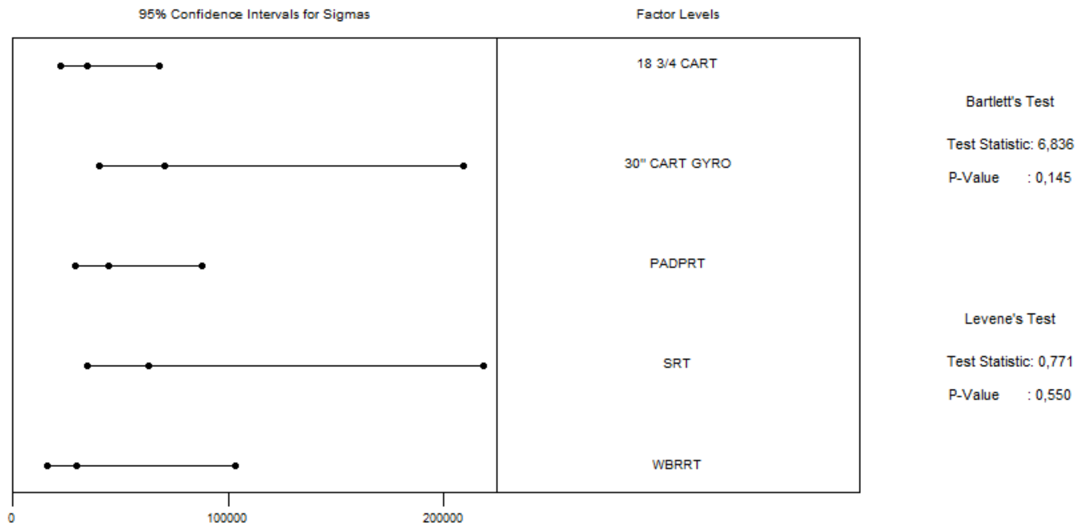


Figure 14: Variation based on tool

The test shows that H_0 cannot be rejected since the P-value>0,05 as showed in Figure 14 above. This means that the "Type of subsea tool" is not contributing to the variation based on this test. The next test to conduct was the "Mood`s Median" to see if the different tools had an influence on the centering. The same rule for rejected the $H_0$ is prevailing in this test as for the "HOV Levene`s".

H_0: The different types of subsea tools have the same median

H_a: The different types of subsea tools have different medians

Also here the P-value is above 0,05 ao H_0 cannot be rejected as showed in Figure 15 below. This means that the "Type of subsea tool" is not contributing to the centering issue. No further actions need to be taken regarding the tool types.

```
Chi-Square = 5,30   DF = 4   P = 0,258

                                         Individual 95,0% CIs
Descript   N<=    N>   Median    Q3-Q1   ---------+---------+---------+-------
18 3/4 C    10     3    43863    51921    (------+--)
30" CART     3     4    62694    68685         (-----+---------------)
PADPRT       6     7    66252    91250     (---------+------)
SRT          2     4    79572    64419         (--------+---------------)
WBRRT        2     4    79467    58405           (------+----)
                                         ---------+---------+---------+-------
                                              50000    100000    150000

Overall median = 57751
```

Figure 15: Mood`s Median test result

A hypothesis test to check if the “Level of maintenance” was significant to the variation and centering issue was also conducted. Both tests gave a P-value below 0,05 (see attachment 6) and the H_0 was rejected which shows that the “Level of maintenance” is definitely a critical factor with respect to the variation and centering issue. The last hypothesis test was conducted to check if the “TC” influenced the variation and centering issue. Both test showed a P-value above 0,05 (see attachment 7) and consequently the “TC” does not have any influence on the variation and centering issue.

To investigate if the cycle time influenced the variation in the maintenance process a regression test was conducted. The result of this test gave a predicted equation for the cost as showed in the regression test in Figure 16 and below:

$$Actual\ cost = 598 + 1{,}27\ TC + 1{,}19\ QC + 1{,}07\ WS - 0{,}77\ DCC$$

The Regression test shows that the different variables, TC, QC, WS and DCC can be used as inputs for predicting future cost. The P-value calculated for this equation shows that TC, QC and WS have a P-value below 0,05 and by that are definitely significant predictors of the cost. The test also calculated a R-Square (R-Sq) value which tells how close the equation is to explain the variation of the response data around its mean. For this equation the R-Sq value is 97,4 which means that 97,4 % of the variation in costs can be explained by the predicted equation showed in Figure 16. The test further calculated the analysis of the variance and this P-value is smaller than 0.05 which means that H_0 is rejected and the equation is a significant of the response (cost) as Figure 16 shows.

H_0: The equation is not a significant predictor of the response

H_a: The equation is a significant predictor of the response

```
The regression equation is
Acctual cost = 598 + 1,27 OTR + 1,19 QC + 1,07 WS - 0,77 DCC

Predictor          Coef       StDev          T        P
Constant            598        2414       0,25    0,806
OTR             1,26820     0,09222      13,75    0,000
QC               1,1912      0,3328       3,58    0,001
WS              1,07307     0,08550      12,55    0,000
DCC              -0,769       1,523      -0,50    0,617

S = 8258        R-Sq = 97,4%     R-Sq(adj) = 97,1%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         4 1,01970E+11 25492439350    373,78    0,000
Residual Error    40  2728040758    68201019
Total             44 1,04698E+11

Source       DF      Seq SS
OTR           1 75373609468
QC            1 14621184268
WS            1 11957593834
DCC           1    17369830

Unusual Observations
Obs       OTR    Acctual         Fit   StDev Fit    Residual     St Resid
 21     24229      66252       94500        2021      -28248       -3,53R
 31      7990      88639       57598        2701       31042        3,98R
 34     33507     207988      203243        6413        4745        0,91 X

R denotes an observation with a large standardized residual
```

Figure 16: Result of the regression test

The tests performed showed that the “Level of maintenance” clearly is a critical factor regarding the variation and that the TC, QC and WS are significant contributor to the cost as showed in Figure 17, while “Type of tool” and “ TC” do not influence the variation.

X1 = TC
X2 = Type of tool
X3 = Level of maintenance
X4 = Cycle time

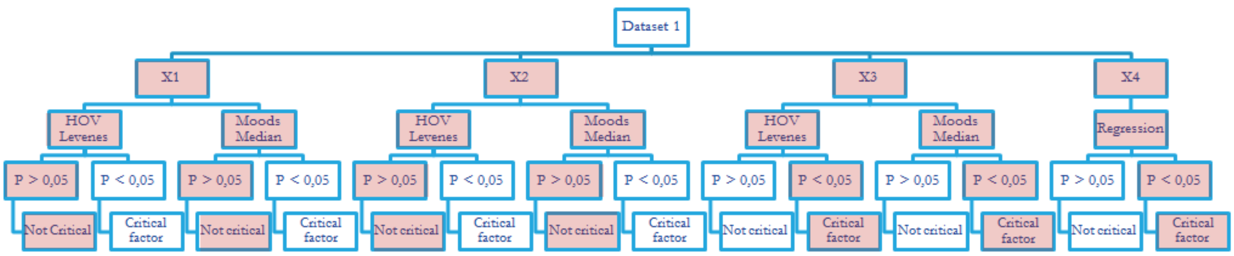


Figure 17: Summary of the different tests in the *Analyze* phase

5.1.4 Improve

From the tests conducted in the *Analyze* phase there was two Xs, X_3 and X_4, that were found to be contributors to the variation in the process. Therefore, counteractions were necessary in order to remove or minimize the Xs. A discussion with BBL and a highly trained Lean employee resulted in Fishbone and VSM tools to apply to improve the process as showed in Table 9.

Table 9: Selected Six Sigma and Lean tools

Critical Xs	Tests	How to improve
X3 = Level of Maintenance	HOV Levenes Test (variation) & Moods Median (Centering issue)	Fish bone
X4 = Cycle time; Hours taken by different departments (QC, TC, WS).	Regression testing.	VSM; identify and remove waste

The first tool applied was the Fishbone and the team was informed about why the Fishbone figure was conducted and how it worked. They came up with several plausible reasons and contributing factors to the variation and these are showed below in Figure 18.

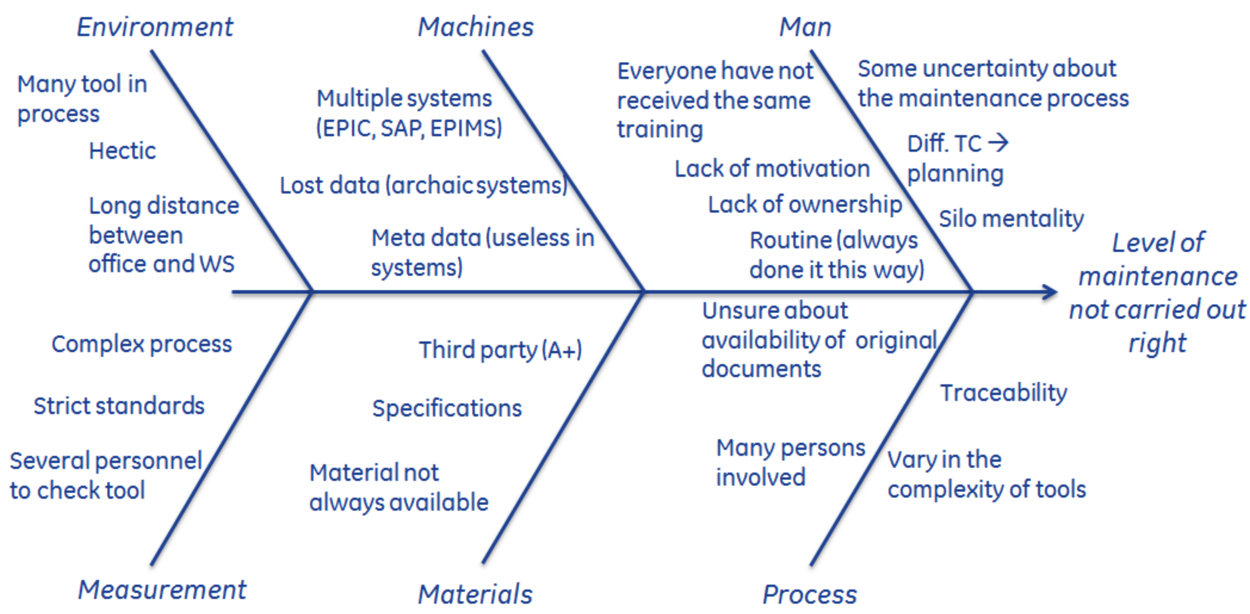


Figure 18: Fishbone result

Especially the topic "*Man*" gave many potential reasons like silo mentality, uncertainty about the maintenance process, hectic environment and different training of the personnel. This indicated that training of the employees with respect to the process and tool types could be beneficial. Training could remove uncertainty related to the maintenance process. More training was also one of the "wants" from the VOC. The maintenance process consists of many steps and involves a lot of employees. In periods where there is a high demand from the customer the work environment often becomes hectic with a lot of tools beeing pushed through the process. Further there are a lot of different systems that need continuous updating so the tools can be tracked. Consequently, the personnel has a load of work to do. Due to poor organizing of original documents it can be challenging to check if an L3 has been performed or not. Instead of spending excessive time on looking through documents without knowing if the necessary documentation will be found, it can be easier to go ahead and perform a L3 to make sure that the tool is ready for being sent back into the field when requested by the Customer. The consequences of a tool not to properly function are enormous and if anything where to happen these papers need to be in order. This unnecessary L3 maintenance is costly for the company due to a significant heavier work load to perform at a L3 than a L1 and L2. The discussion further revealed uncertainty around the sequence of the different steps of the process and how to conduct the maintenance level correctly. Such uncertainties around the process increase the cycle time due to waiting and needless steps. The process will never reach its full potential if the personnel are uncertain about the work tasks.

The team members voted for traceability of components in tools and availability of original documents (L3) in SAP as the main factors for incorrect maintenance level execution. While equally training program came third. Based on the common agreement from the team members upon the three factors these were selected to be improved.

To enhance the traceability of the components it was decided to change the current SNR list. The personnel lists the components in the SNR list when they disassemble the tool. However, there has been cases were the list does not correspond with the actual components of the tool. A reason for this can be that the personnel have forgotten to change the list when they re-assembled the tool with new components. A solution would be to list both ingoing (disassemble) and outgoing (re-assemble) components of the tool. The SNR list would then have both one column for ingoing, as the SNR list looks to day and another list for the outgoing components in the tool. If there are any changed components from the ingoing and outgoing tool this would be visualized in the documents since the ingoing and outgoing column would have different component serial numbers. The new step of filling out outgoing SNR list needs to be added so an instruction of how to carry out the SNR list in the future were made as showed in Figure 19.

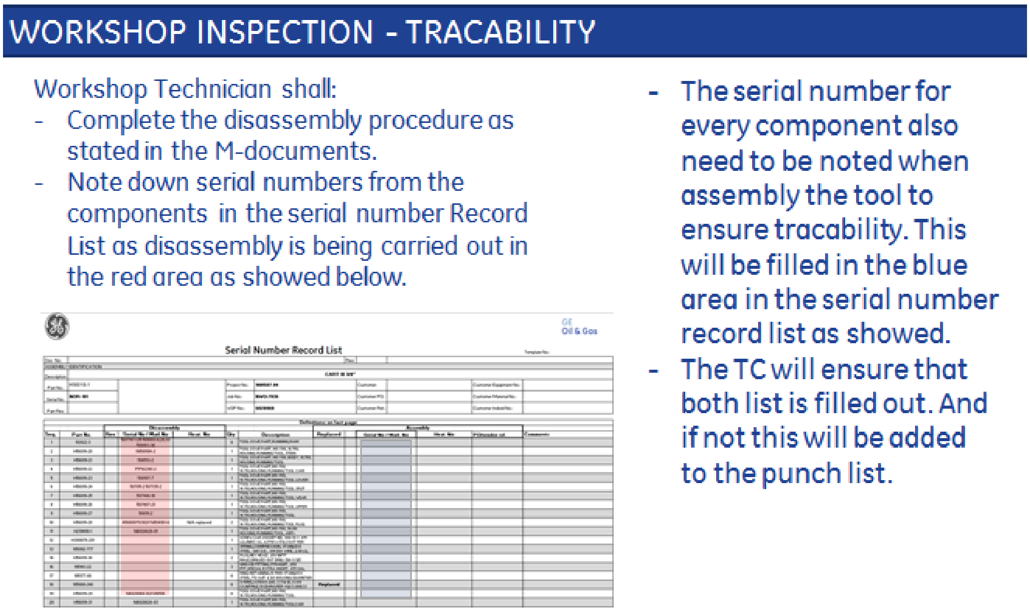


Figure 19: Traceability instruction sheet

There were not sufficient time to initiate action regarding the uncertainty about the original documents, but a suggestion of how to do this was given. To improve this the original documents for the tools should be made available in a shared system that the personnel use. At GE every employee need to have a SAP account and also have basic understanding for the system. The maintenance process mainly uses SAP for the projects and updating the status of the tool. Therefore, a solution can be to place the original documents for each tool in SAP. The original document for the tool, which is the latest L3 performed, should be available in each main file for the tool in SAP. Such a solution will make it easier for the personnel to check when it has been through a L3 and further ensure the correct maintenance level so no unnecessary maintenance is performed. An example of unnecessary maintenance is when the staff in the WS does not find the documentation of the L3 on the tool to maintain. A new L3 will then be required to make sure that the state of the tool is within the required demands. Accordingly, the original documentation (L3) should be stored in SAP where the personnel can easily find and check the documentation. This will minimize and/or remove the uncertainty around the maintenance level. The suggestion was accepted by the managers and will be implemented in SAP.

The personnel also wanted to receive similar training and have a course for the maintenance process. The employees wished to learn more about the different type of tools. Also a quick reminder of the importance of the traceability of the components and the new SNR List was added by the author as showed in Figure 20. This training suggestion was not implemented in the process due to limited time but it was proposed for the managers and the BBL.

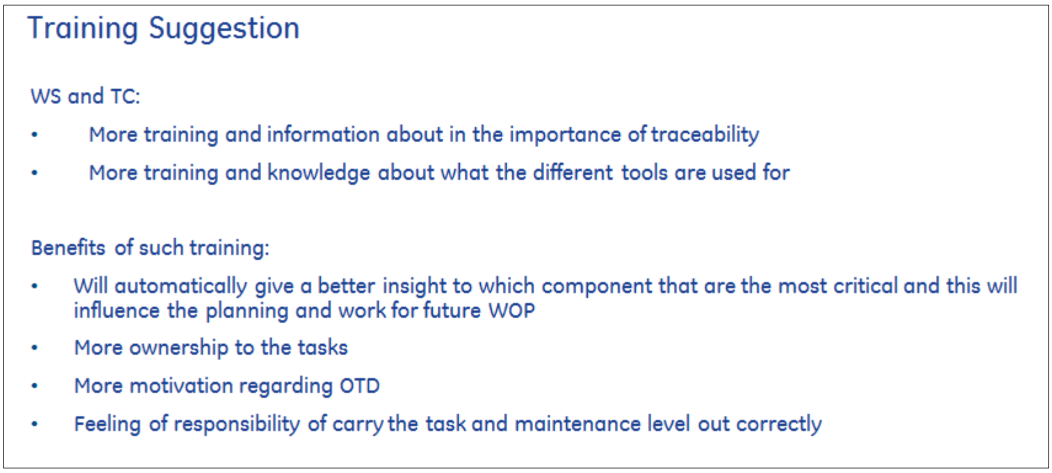


Figure 20: Training suggestion

The Lean tool VSM was conducted where the author followed tools through the process. This process revealed several factors that can impact the cycle time including waiting and over-processing as showed in the pictures in Figure 21.

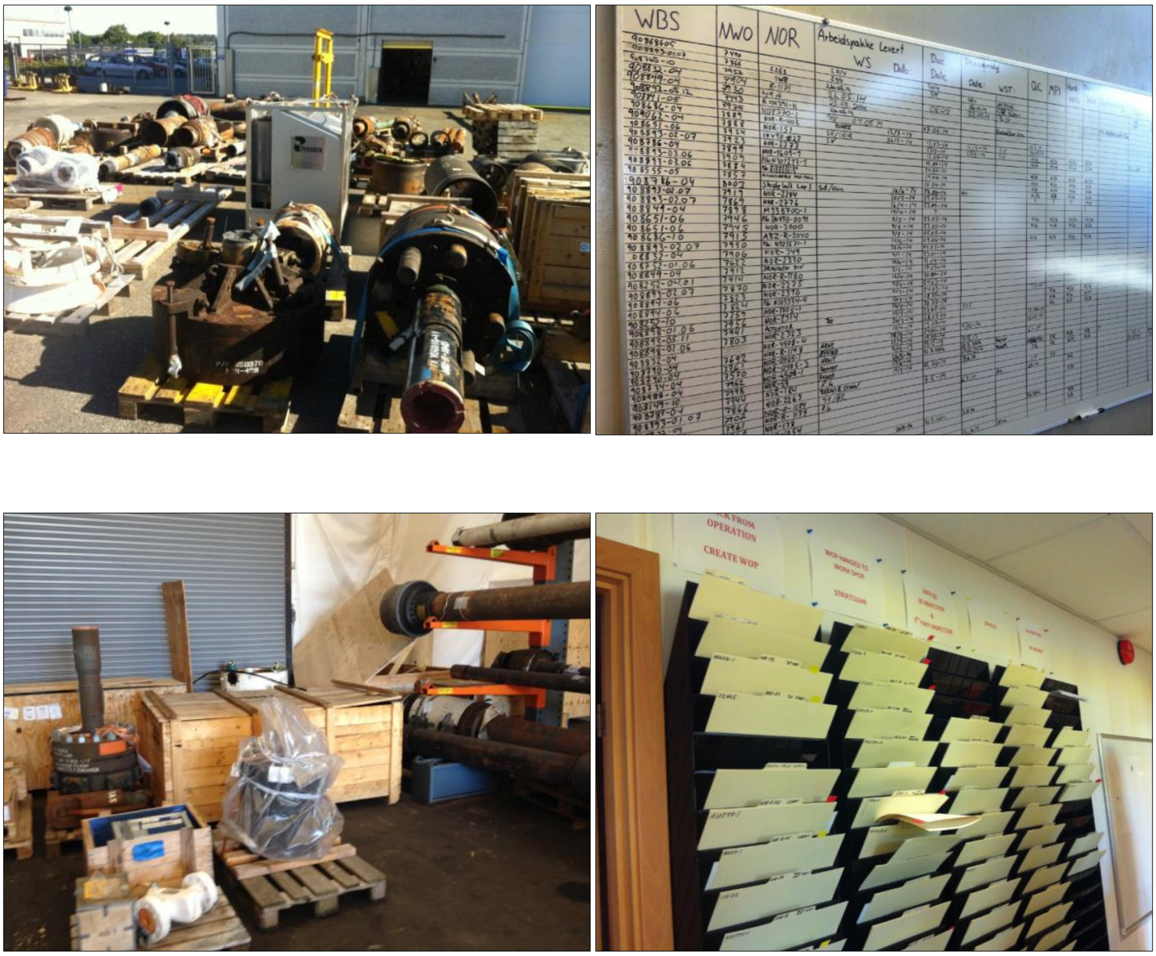


Figure 21: Documented waste in the maintenance process

The process revealed that there was no fixed procedure on the steps in the maintenance process. Consequently, it was difficult to make a process map for the current state. However, the process showed that the current state of the maintenance process had the following issues:

- Ownership issues
- Some uncertainty around the WS steps
- Over-processing
- Unnecessary subsea tool pushed through
- Tools moved around due to space constrains
- Inventory accumulates
- Waiting for the tool due to outsourcing and tools that needs spare part

The VSM discovered ownership issues and personnel that were not entirely sure about the steps in the maintenance process. Also bothersome processes and over processing regarding the overview of the tools in the WS was discovered. There was also poor communication between the departments and the consequence was often bottlenecks. Subsea tools that were booked for storage was pushed through the maintenance process simultaneously with other subsea tools that were needed for operations which gave extra pressure on the WS personnel. The inventory in the WS was not structured enough, and equipment did not have a fixed place. There was also some waiting due to tools that needed to be coated by a third party service or spare parts that had not arrived. The time it took for the investigated tools to go through the whole process had an estimated time on 72 days, where 64 days were non-value-added and 8 days with value-adding-step. Based on the findings a new future state VSM was made and converted into a process map as showed in Figure 22. Especially the ownership of the different tasks was an issue that needed to be addressed which is solved in the new future state map.

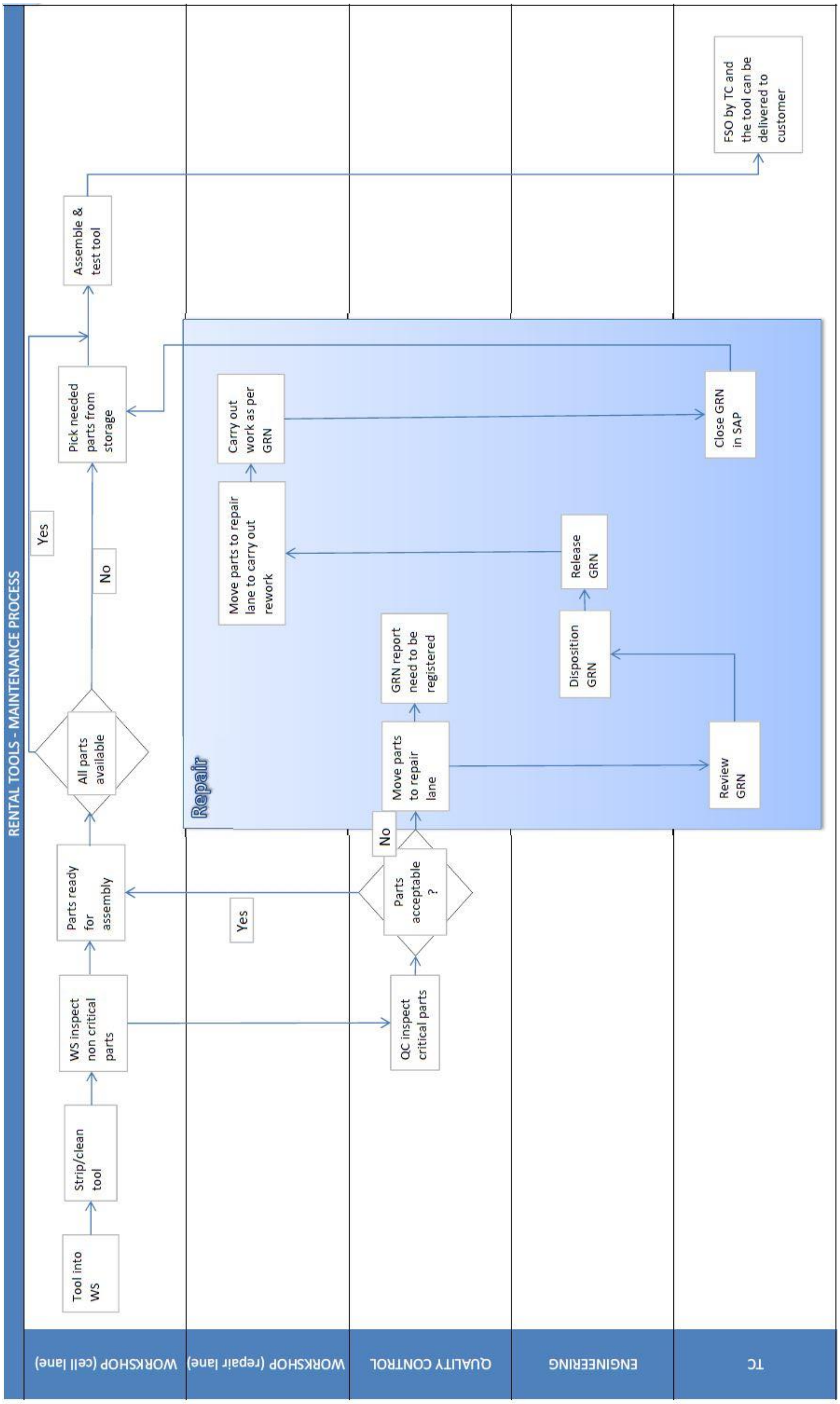


Figure 22: Future maintenance process

The process map contains two different symbols which have different meaning:

- Decision
- Process step

The decision symbol will contain two possible options, as shown in the figure above this can be e.g. all parts acceptable? If yes, the tool can be assembled but if they are not accepted they need to be repaired. The process step symbols show which step the maintenance process contains. The new process map for the maintenance process clearly visualizes who has responsibilities for the different tasks. Continuous updating of the tool and its progress will also be required so it can be traced during the maintenance process to know which steps it has been through.

To see if the implemented measures have worked as intended a new sample needs to be collected and tested as the previous sample. Due to the natural flow work at GE a hypothetical dataset had to be used in order to investigate if the process was improved or not. In order to demonstrate different outcomes of the Six Sigma project there will be used two hypothetical datasets. Dataset 1 will yield an improved result while Dataset 2 will not show any improvements as illustrated in Figure 23 below.

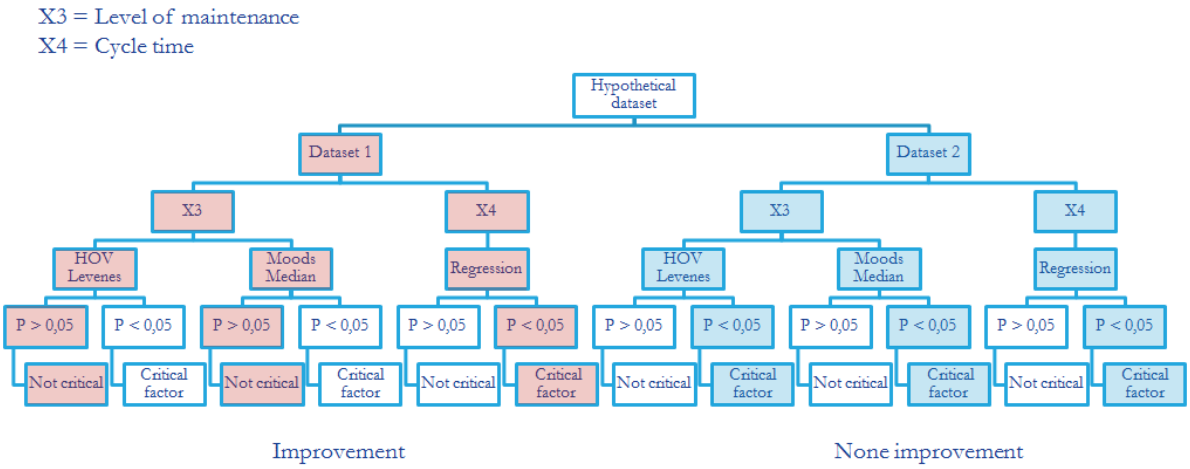


Figure 23: Result of analysis tests of dataset 1 and 2

The datasets will go through the same tests as the previous sample and the new P-values will be compared up against the previous P-values to look for improvements. First of all, Dataset 1 was run through the Process Performance test to see how the process behaved after implement the measures. The result showed a process more in control and a decreased DPMO for all the maintenance levels. The process is still defined as unstable since there is some point in the MR chart that is outside the limits sat by GE. Nevertheless, the process is considered much more reliable now than in the previous Process Performance tests. With minor improvements with respect to the cycle time the process will be stable and under control. Further, Dataset 1 shows improvement for X3 – Level of maintenance, both HOV and Moods Median have a P-value higher than 0,05 meaning that this is no longer a critical factor. In other words, the "Level of maintenance" does not affect the variation in the process anymore. The P-value from the regression has been enhanced but is still below 0,05, which means that the cycle time and the hours used from the different departments are still significant predictors of the cost. Even though just one of the Xs was removed from the process it is still defined as successful since the goal is to minimize or remove the Xs. In other words, the Y, which is the desired outcome of the Six Sigma project which was to reduce cycle time, is achieved. Dataset 2 showed no improvement nor in the Process Performance test or for the "Level of maintenance" or the "Cycle time". In HOV Levenes and Moods median both P-values are below 0,05 which means they are still a critical factor and definitely contributing to the variation issue in the process. This means that the improvements that were implemented have not minimized or removed the variation. A point to remember is the heart of the DMAIC-model, as mention in Chapter 2., which is the collected data. These data are the most crucial and critical in the model and they need to be correct. Since there are no improvements in Dataset 2, this indicates that the data gathered earlier in Chapter 4 may be faulty and/or contain too much uncertainty. When the project has not managed to eliminate the variation in the process a decision regarding further work will be necessary. There are three possible outcome of such a result, either to toss the project, redo it or to do a DFSS project. There are several factors like cost, time, benefits and consequences that affect which of the three possible outcomes that are decided upon. To determine this both top management and BBL should be involved in the decision.

5.1.5 Control

From the previous phase it was only Dataset 1 that showed improvements and to maintain these improvements the process need a control plan. To do so it will be necessary to distribute the responsibilities on to the employees to assure long-term process control.

For "Level of maintenance" it is two factors that need to be controlled: (1) traceability in SNR list and (2) original documents available in SAP. For traceability the WS personnel will have the responsibility for filling in both ingoing and outgoing components of the different tools. The TC will go through the WOP before the tool receives a FSO. If there is something that is not done after the instruction or standards the TC will make a Punch List were the remaining actions are listed which need to be performed before the tool will get a FSO. The SRTP will be given the responsibility to put every relevant L3 into SAP, while the TCs will have the ongoing responsibility of update SAP with new L3s performed. It is first of all the already existing L3 that is necessary to get entered into SAP. The WS and TC personnel can then easily check when the tool had the last L3 to ensure which maintenance level that will be required to perform.

For "Cycle time" the new process map needs to be followed. The M-document in the WOP describes how the tool should be disassembled, maintained and re-assembled. The new process map follows the M-document and shows which employees that has the responsibility for the different steps. It is also possible to sign off the different activities in the M-document. This means that when an employee from the WS has worked on the tool, e.g. disassembled it, the person should sign the M-document with name and date. This ensures that the action is executed and it will be easy to see if the steps are followed as described in the future state map. It will be necessary with an introduction to the process map to inform about how the process should be performed and answer questions from the personnel if any. After implementing the new process map the TC will check the M-document to see if there is any irregularities in the sequence of steps from the process. If the TC finds any errors an examination is needed to discover if there has been uncertainty around the process, shortcuts or an unexpected event that caused it.

To ensure that the process is under control and stable random sampling is necessary to see if the process is within the target costs, USLs, sat by GE for each maintenance level. If none of the projects exceed the USLs the process is under control. Then, if GE wishes to decrease the cycle time and target cost further, this will be the right time to look at new initiative and actions. If the outcome of the process shows any other results than what is expected, an assessment of the outcome and investigation of the process would be essential. This is necessary to establish if the error was created by special or common cause of variation to localize the defect. If the result is a special cause the action will be required to remove the variation. And based on the result of this, further action may be required to restore the process.

The control plan in Table 10 below shows the required actions to ensure that the benefits from the project are maintained.

Table 10: Control plan

Definition of work	Action Completion days	Action Owner
Ensure that every tool has original documents available in SAP	30	SRTP
When a maintenance check is executed the TC must update original documents in SAP with the latest one	Continuously	TC
Fill in both ingoing and outgoing SNR list to ensure traceability of every component in the tool	Continuously	WS
Check the SNR list before signing FSO	Continuously	TC
Take random samples from the projects in the maintenance process to investigate if they are within the USL set by GE.	Continuously	SRTP

5.2 Result

This chapter will give a brief overview of the summary of the Six Sigma project and main findings in this thesis.

5.2.1 Summary of the Six Sigma Project

The Six Sigma project had a main goal of reducing the cycle time in the maintenance process and by that also reduce the cost. It was early in the process of this project stated that there were a problem in the maintenance process. The cost of projects conducted in 2015 in the maintenance process was compared to the cost goal for 2016 set by GE. This comparison showed great improvement potential and based on this the Six Sigma project was accepted by the BBL at GE.

When the approval was received, a data collection to gather all necessary information and data about the process was started. It was collected information about 45 projects conducted in 2015. The data gave the baseline for the performance in the maintenance process. Furthermore, hypothesis and regression tests were conducted to prove that there were some factors, Xs, which clearly affected the variation in the process. There were two Xs, X_3 "level of maintenance " and X_4 "cycle time" as showed in Table 11, that needed to be addressed. And to improve these factors a fishbone for "level of maintenance" and a VSM for "cycle time" was conducted.

Table 11: The process of removing the Xs

Critical Xs	Tests	How to improve	Results
X3 = Level of Maintenance	HOV Levenes Test (variation) & Moods Median (Centering issue)	Fish bone	Original documents available in SAP where all personnel can verify which maintenance level that is required. Traceability of the components in the SNR lists.
X4 = Cycle time; Hours taken by different departments (QC, TC, WS).	Regression testing.	VSM; identify and remove waste	No confusing regarding the steps in maintenance process or the responsibilities of them.

The results of these Six Sigma and Lean tools had to be implemented in the process and a new sample with projects would be necessary to see if the improvements actually worked. Since it would take some time to see if there actual were any improvements due to the natural workflow at GE, two hypothetical datasets was made with two different outcomes. Dataset 1 showed improvements while Dataset 2 showed no improvements. A control plan for Dataset 1 was made to ensure that improvements were maintained after closing the Six Sigma project. A decision on whether to do a DMADV, redo the project, or scrap the project completely is needed for Dataset 2. A redo of the project or a DMADV would be recommended since there is stated earlier that there is a problem in the maintenance process, and this problem causes variation in the process which should be addressed.

5.2.2 Main Findings

This chapter will look at the result of the thesis relative to the problem description. The Six Sigma project was conducted using both Six Sigma and Lean tools to identify benefits and potential shortcomings when combining these methods.

From Dataset 1 there are clear improvements after conducting Fishbone and VSM to ensure right maintenance level performed and reduction in hours to reduce the cycle time. Both tools have showed improvements, even though only one of the Xs was removed from Dataset 1. The traceability of the different parts in the tools and the availability of documents in SAP has made the decision of right maintenance level easier and there has not been performed any unnecessary L3 due to lost documents or uncertainty. The new future state map gives a clear instruction regarding the order of steps in the maintenance process. Dataset 2 showed no improvements which can indicate that the data gathered are too uncertain. Data sets which are not correct will yield wrong solutions to the problem and therefore not improve the process as intended. In that case the Six Sigma and Lean tools would not work optimal and fail to give the necessary improvements in the right areas.

By the experience of the cumbersome way of collecting the hours the author suggests the input requirements in SAP regarding hours should be more user-friendly. This can be done by organizing the structure in SAP differently. A solution could be that every hour registered in SAP need to be connected to a project as showed in Figure 24 below.

Level one	Level two	Level three			
909700-NOR-184					
909700-NOR-173					
909700-NOR-R-1167					
	01.01.2015 L3				
	01.03.2015 L1				
	01.05.2015 L1				
	01.06.2015 L2				
	01.07.2015 L2				
	01.08.2015 L2				
		Description	**Date**	**CC**	**Hours**
		TC	01.08.2015	1050117	0,50
		WS	03.08.2015	1050220	6,75
		WS	04.08.2015	1050230	3,50
		QC	05.08.2015	1050212	5,00
		TC	07.08.2015	1050117	1,50
		WS	08.08.2015	1050230	4,50
		WS	09.08.2015	1050230	2,00
		QC	10.08.2015	1050212	3,00
		WS	11.08.2015	1050220	2,00
		TC	12.08.2015	1050117	1,50
		MA	13.08.2015	1050300	1,00
		Engineering	14.08.2015	1020860	1,50
		DC	15.08.2015	1050213	2,00
	01.09.2015 L2				
	01.12.2015 L2				
909700-NOR-165					
909700-NOR-187					

Figure 24: Possible WBS structure in SAP

First of all, the tool that is investigated needs to be selected in the main list (level one). Every project related to this tool will now appear in a new list (level two). The projects are separated by date and by maintenance level. A specific project can be selected and every hour registered on this project will be visible. This structure will make it easier to collect hours in the future.

Both the Lean and Six Sigma tool has improved the maintenance process as showed in Table 12 below. The solution from the Fishbone figure managed to remove the "level of maintenance" as a contributing factor to the variation. While the VSM from lean showed improvements but was not sufficient to completely remove it from the process. Further actions with other tools will be necessary to be able to eliminate this factor completely.

Table 12: Result of the Six Sigma and Lean tools

Method	Tool	Result
Six Sigma	Fishbone	Removing variation in the process by; removed uncertainty around the level of maintenance level by implementing original documents in SAP. Ensure traceability of every component in the different subsea tools. Suggested further training for the employees.
Lean	Value Stream Map	Speeded up the process by; identify and remove waste in the maintenance process and give clear instruction on the sequence of the maintenance steps.

6.0 Discussion

This thesis has investigated benefits and challenges of combining a Lean tool in a Six Sigma project at a maintenance process at GE. It has been conducted a Six Sigma project where two critical Xs were found to have an impact on the variation in the maintenance process. To see if these factors could be improved tools from both Six Sigma and Lean has been utilized. Decisions made throughout the thesis are discussed and suggestions for further work are proposed.

The sample size of 45 projects was set based on the authors capacity and the available WOPs. From the *Analyze* phase in Chapter 4 it was revealed two factors that influenced the variation in the process. If a larger sample was to be chosen it could have unveiled other factors as well. However, for this thesis a larger sample would have been too demanding. On the other hand, if the project had been conducted by a team a larger sample would have been manageable. Because of the current structure in SAP the sample size was also dependent on the availability of WOPs at GE archive. If the structure in SAP had been different and the need for the WOPs where removed a larger sample could have been selected. This would simplify the process of collecting hours and the amount of work to collect the required data would have decreased considerably.

As mentioned above, one of the factors affecting the sample size was the availability of WOPs at GE which appeared to be a challenge. The need for the WOPs was not revealed before after starting to collect the hours. The author knew that every hour was available but was not aware of how the hours in SAP were structured. Due to this, the availability of correct data in SAP was not taken into consideration when deciding which data that would be necessary. To ensure availability and awareness of how to collect data these factors should be focused on when deciding which data to select. If they are not, extra work would most likely be necessary. On the contrary if combined together and counted for this will give a more efficient data collection process.

Data certainty is alpha and omega for a Six Sigma project. The result of a Six Sigma project is highly sensitive to the data accuracy. If the collected data contains too much uncertainty it can lead to the use of incorrect Six Sigma tools. The applied Six Sigma tool can then give the wrong solution to the problem. Lean on the other hand is not as dependent on the accuracy of the data and can give feasible solutions despite the uncertain data. The greatest challenge regarding data uncertainty for this thesis will be the accuracy for the dates of the hours registered upon the different tools. The hours collected are based on the authors research of which project they belong to. Should it turn out that the data contains too much uncertainty the tests and subsequent solutions will be based on wrong assumptions. Then the implemented improvements will most likely not give the results that were intended. This can be an explanation to why Dataset 2 in the *Improve* phase in Chapter 4 did not show any improvements of the maintenance process. Based on this the new suggested SAP structure should be introduced. The new SAP structure can be initiated with minor improvements and the possible benefits gained from this are high compared to the cost. It will make it easier to collect data from the maintenance process in the future.

Furthermore, it would give a higher accuracy with respect to which projects the hours belong to. Consequently, an improved WBS in SAP would most likely give more accurate and precise data which in turn would give future projects a higher chance to be successful. However, the personnel can still enter their hours on the wrong project or tool. This is an uncertainty in the maintenance process that will be difficult to remove completely. On the other hand, if RTD wishes to keep the current structure in SAP, this will demand higher discipline regarding the moment of when the hours are entered in SAP. The personnel would then need to enter the hours at the end of each work-day. Generally, in a hectic work day it may be difficult to accomplish such a measure. The uncertainty of hours will still be present in both structures, but the new structure provides an enhanced system with less uncertainty.

The main focus for selecting target costs for the maintenance process was to decide upon how many targets costs to set and the size of each one. The managers had set one optimistic target cost but through the tests in the *Analyze* phase in Chapter 4 the author discovered that this was not adequate due to huge difference in cost between each maintenance level. Three different cost targets up against the different maintenance levels were chosen to have more realistic targets. Some may argue that to be more efficient and reduce cost, optimistic targets are necessary to motivate the personnel, but it is also important that the targets are realistic. If there is no way that the personnel will reach the target no matter what they do, the motivation will vanish and the reliance and confidence upon the managers can be damaged. On the contrary, it is important to not make too simple targets so that the personnel do not even have to improve before the targets are reached. The figure 10 of the three new targets level showed in Chapter 4 clearly shows that there are some of the projects that have an enormous cost and it is here the personnel should try to reduce the cost first. When every project is within the USL sat by GE, new targets limits can be sat to improve the process further. But first of all, it is necessary to get the process under control and stabilize it around these targets.

The tools from Lean and Six Sigma were based upon a discussion with the BBL and a Lean-educated employee where the joint knowledge of the group and logical reasoning were used to select which tools to apply. On one hand, the importance of being authorized in Six Sigma projects or highly trained in Lean would maybe not be necessary to *conduct* the Fishbone figure or VSM since the execution is relatively easy. On the other hand, the knowledge about *why* these would be the best suited improvement tools for this thesis and not one of the many other tools in both Lean and Six Sigma was based upon knowledge, experience and logical reasoning by the BBL and the Lean-educated employee. Employees that do not have that training and understanding of how the different tools works and the pros and cons that follows with them would probably not manage to choose the most appropriate tools to use. For example a Fishbone figure is simple to conduct and usually gets a lot of engagement and information from the team, as well as very little training is required to utilize this tool. However, if the team is put together improperly the result of the Fishbone figure could become useless. Eventually, the solution gained from the chosen tools would not give the optimum result. Hence, the knowledge from BBL and an educated Lean employee will be necessary to make the right assumptions and choose the tools that give the best result for the project.

The different tools applied in this thesis gave many suggestions of why there was variation in the process. From the Fishbone figure, lack of motivation, ownership issues, silo mentality, uncertainty around the process and lack of sufficient training were suggested as some of the contributing factors from Figure 18. These factors can all be connected with the employees, which give an indication that it should be focus on the personnel in the maintenance process. The maintenance process is a process that is often hectic and where lot of tools need to go through the process simultaneously due to high demand. When the personnel have a lot of work to do and also experience issues like the ones mentioned above, the process will never reach its full potential. First of all, more training should be initiated for the employees both with respect to the maintenance process and also how the different tool types are used in the field. This would give the personnel more self-confidence regarding the uncertainty of the process and could also increase the overall motivation. When the process is clearly described and the employees are aware of their area of responsibility, together with enhanced training and better understanding of the whole process, this can help remove the ownership issue and give a more efficient workflow. There is a relatively small amount of work that needs to be done to improve these problem areas. The maintenance process needs a proper clarification and this would probably gain the process significantly. If not, the maintenance process will have difficulties to improve at all. This can result in employees that only do what is *necessary* and do not really care about the product that is to be delivered. It will be difficult to grow the company if the employees do not support you. Also, a highly engaged management can also boost the motivation and ownership of the maintenance process for the staff. Old routines need to step aside for the new and improved way of execute the maintenance process. The mindset of the personnel need to change and it is the managers job to make that happen and lead the way into a new and improved performance of the maintenance process. If not, the staff will often just stick to the old process because this is the familiar way of conducting maintenance. This was also stated in the literature review in Chapter 2 to be one of the success factors for a Six Sigma project and the author does also share this opinion after conducting this thesis. The importance of support, guidance and motivation throughout this thesis has been essential for the result.

Sub-optimization in a company can occur when the company is not as successful as it could be. This is due to departments/employees that work in a silo only focusing on its/their own success and not what is best for the company as a whole. [36]. Lack of ownership and severity of not considering at the entire maintenance process as one can also be a factor for this mentality. These issues were made visible through both the Fishbone figure and the VSM. More motivation, training and understanding of the whole process can contribute to less sub-optimization. It is important that the personnel work together on delivering the subsea tools to the customer instead of thinking “I have done my part” and “not my responsibility”. If the employees, through more training, receive more sense of achievement and enjoyment this could give a motivated staff. Motivation and inspiration gives energy to the personnel by satisfying fundamental human needs for belonging, goal achievement and a feeling of self-control. On the contrary, if these needs are not fulfilled the removal of sub-optimization can be difficult. If the employees are not called attention to the superior goal of the company the sub-optimization can go on and influence the company goal further. Actions should be made due to the fact that motivated personnel would do their best to try to reach the goal sat by the managers [37].

Dataset 1 showed that there is necessary with further improvements to remove the cycle time, i.e. the hours used, as a factor for the variation in the process. A tool that can help improve the cycle time can be 5S. This is a Lean tool that the author would have implemented if there had been sufficient time. This tool organizes the work area in such a way that it becomes intuitive and easy to use. It consist of 5 acronyms which starts on S and the main objective is to; distinguish needed items from the unneeded (Sort), keep the items in the correct place (Set in order), keep the workplace clean (Shine), make the three first S`s an habit for the personnel (Standardize) and ensure that the procedure is sustained (Sustain). It would have been interesting to see how this tool would have influenced the maintenance process both in a more structured way to perform the maintenance process and the fact that the cycle time probably would decrease even more or removed completely.

Dataset 2, who did not show any improvements after implementing the solutions, was not taken into any further assessment. However a Six Sigma project that does not show any improvements in the *Improve* phase should be assessed with respect to the reliability of the input data and the implementing solutions. Also, if there had been time it would have been interesting to look at the reasons for why the solution did not work as planned. It can be faulty data from the *Measure* phase or the fact that the process needs a DMADV to actually manage to improve at all. One way or another, the proven variation in the process needs to be removed so that the process can deliver high quality tools within the agreed date. If the variation is not addressed the sigma level will not improve and the growth of the company will not reach the full potential.

Six Sigma has in general a high complexity when it comes to execution and necessary training and education are required before the person will receive the first belt in the Six Sigma belt hierarchy. This enormous amount of training before any personnel are approved to conduct Six Sigma projects can become an obstacle for companies new to Six Sigma. The cost of training and implementing the new method of how to do business can be of such a character that some companies do not have the financial ability to initiate it. The companies that wish to utilize Six Sigma also need to investigate the benefits against the costs of such an implementation. Lean on the contrary is a relatively simple method to conduct which do not required a lot of training or knowledge to execute. The Lean tool, VSM, clearly showed that there was waste in the maintenance process that should be removed. Lean and Six Sigma focus on different improvement and problem areas, and factors that Lean revealed Six Sigma may not have been able to find and vice versa. As an example Lean discovered a lot of waiting in the maintenance process as a possible factor for long cycle time and this was not brought to light by Six Sigma. Lean easily exposes different challenges in the VSM and addressed them with a future state map. This will most likely reduce the cycle time of the maintenance process at GE. Lean has a "just-do-it" mentality whereas Six Sigma needs more information and proof of an actually problem before starting any projects. This Lean approach and "just do it" mentality can be a challenge to overcome if the managers are trained in Six Sigma and want a more proof-based comfort level before any changes or improvements is initiated. Lean employees that start Six Sigma training can have a mindset where the required proof based Six Sigma methodology is abandoned in favor of the lower threshold criteria of startup projects by Lean. This is a big difference in these methods that was also experienced by the author during this thesis. The thresholds criteria of conducting the Six Sigma project and utilize the Six Sigma tools were much higher compared to utilize the VSM from Lean. This was also stated by the BBL that the allowance for Six Sigma generally is much higher than for Lean. To start any Six Sigma project there needs to thoroughly investigated that there actually is a problem in the process, while Lean has lower acceptance for starting such improvement work. A reason for this can be that Six Sigma has a fixed method of how to conduct a project; either with DMAIC- or DMADV-model. These are both time-consuming and costly projects and therefore projects that do not show evidence of any errors or indications of a problem should not be accepted. Lean on the other hand has not these directions on how to perform the different tools and the acceptance level for utilize these tools are usually lower because of this. Another challenge regarding the combination of these methods can be the big amount of information, training and execution that the personnel need to have control off. Especially the training for Six Sigma is demanding and time consuming while Lean can be conducted and implemented without a large amount of training required. Knowledge about how the different tools can complement each other will also be necessary to ensure that the tools are fully utilized and that the right tools are selected from both methods when combined. Also, too much focus on the methods instead of the process to be improved can be a undesired outcome due to all the guidelines and steps to follow. It can become a lot of extra administration work and procedures to follow where the problem of the process diminishes in the requirements of these methods. However, the combination of Lean tools in a Six Sigma project gives both removal of variation in the process by Six Sigma as well as a maintenance process that runs smoother by Lean. Where Six Sigma focuses on variation Lean contributes with speeding up the process and solves other issue that Six Sigma does not concentrate on. Because of the different focus areas of Lean and Six Sigma a combination of the two will most likely give a better result than implementing just one of them as mention in the literature review in Chapter 1. Where one method is weak the other method is strong and by using both methods the result will be improved. This thesis has utilized the benefits from both Lean and Six Sigma and has obtained a result that appears to be better than just implementing one of the methods.

Another point when conducting Six Sigma projects where Lean tools are applied is that those projects often actually are Lean Six Sigma projects. A Six Sigma project where Lean tools are applied can also be categorized as a Lean Six Sigma project. The definitions on these different methods of conducting Six Sigma project, either with Lean tools or as a Lean Six Sigma project, are often diffuse. There are no clear guidelines to separate these two and both can be argued for in this thesis. However, this project has used DMAIC as a main frame, and the whole process is based upon the Six Sigma method of executing a project, so Lean has not been used as basis. The contribution of Lean was the VSM to improve the Xs. Usually, a more equal contribution from the two methods is common in order to categorize the project as a Lean Six Sigma project. Yet, the VSM provided focus on flow and speed in the process which can give good arguments for calling this a Lean Six Sigma project. Nevertheless, the project conducted in this thesis has, by the authors opinion a clear focus on Six Sigma where Lean is only focused by the VSM. On the basis of this, the project is categorized as a Six Sigma project where a Lean tool has been utilized. However, if several Lean tools had been used in this project, e.g. include the 5S as well, it would have given more weight on the Lean Six Sigma argument. The combination of a Six Sigma project and a Lean tool has not been performed in GE Oil & Gas by the authors knowledge.

The author has gained a large amount of knowledge about both Six Sigma and Lean during this thesis, yet there are heaps of information and knowledge that still is required before conducting such a project completely alone. Nevertheless, the author experienced that the DMAIC model gives a solid foundation for an improvement project where different tools can be applied and not just limited to Six Sigma or Lean tools. On the other hand, if the project would have Lean as a foundation where Six Sigma tools were applied it probably would have been more difficult to decide upon the proper Six Sigma tool since they need to be based upon statistical data which Lean does not require. However, Lean has also showed to be more manageable for an apprentice in the improvement world as stated in the literature review. Lean and Six Sigma tools are different in how they approach and what area they focus on when improving. The combination of these methods has given the author a chance to improve both cycle time by Lean and the variation in the process by Six Sigma. Utilizing just one of these methods would result in improvements in either the variation or the speed of the process. However, it is also important to not take on to much at the same time. Clearly defined projects and well-chosen teams to improve the areas are essential for successful projects as well as good support from the top managers. The literature review stated that the combination of Lean and Six Sigma would give more benefits and greater results than using just one of the method and this thesis draws the same conclusion.

6.1 Reliability and Generalization of the Result

The reliability and generalization of the work of this thesis need to be assessed to validate the result and conclusion. Most of the work with this thesis is performed by the author alone and because of that it has been necessary to simplify the project in some areas. This could have affected the result in that grade that not all necessary information about the process has been discovered. Six Sigma projects are usually performed by a team and they usually have some level of training in Six Sigma. The fact that the author does not have any training in Six Sigma may also influence the procedure of how this Six Sigma project has been executed. However, the author has updated the BBL continuously through the thesis to ensure that the project is moving in the right direction. The reliability of the project was discussed and based on the authors knowledge about the process it was concluded that the project is reliable enough to proceed. The acceptance of the reliability of the project would most likely not been approved if the author had not had knowledge of the process in advance due to severe amount of information, processes and systems to have control over in order to understand the maintenance process.

Another important point to discuss is the generalization of the result and conclusion of the thesis. The findings in this thesis are applicable for the maintenance process at GE. However, this does not mean that the result of this thesis can be generalized for a randomly chosen process at another company. In order for the result to be generalized several Six Sigma projects like this one should be executed in different processes at different companies. It would be interesting to investigate if similar projects in other companies would give the same results. However, the findings in this thesis are comparable to the results from the literature review: i.e. that a Lean and Six Sigma combination achieves better results. Nevertheless, the result from this thesis and the conducted Six Sigma project is primarily relevant for the maintenance process at GE.

The different tasks where other personnel have been required to gain information about the process, has been chosen by the author alone. In addition the information gained is interpreted only by the author. There is a probability of different assessment regarding selection of personnel for the different tasks like VOC, Fishbone and VSM regarding the interpretation of the result of these if this project would have been executed by another person or a team. It could have been favorable with a team member to discuss and assess the information and work process to ensure that both understood it the same way. The supervisors have given their advice but the result and conclusion is still only based on the authors interpretation. A team would have been more certain about the core and essence of the information given by the personnel to be correct since they would have the opportunity to discuss this. If it was conducted several similar projects like this to assess the generalization of the result it would be desirable with a Six Sigma team to consolidate the information gained.

The tasks in the Six Sigma project that required other personnel from the maintenance process was chosen based upon the authors opinion on what personnel that would benefit the assignment most. The author has in the different tasks asked open questions and stayed neutral to not affect the personnel. Nevertheless, the author know many of the chosen personnel because of earlier internship and this can have influenced the answers and information from the personnel without them realizing it.

7.0 Conclusion

The objective of this thesis was to look at the benefits and challenges of combining Lean tools with a Six Sigma project at GE facilities in Stavanger. The thesis has successfully confirmed that a combination of these two methods will give an improved end-result due to a broader focus area. The main findings from the thesis are summarized and included in this chapter.

The thesis has executed a Six Sigma project in co-operation with GE where the main objective was to reduce the cycle time in a maintenance process. The work found two critical factors that had a significant impact on the variation in the process which in turn affects the cycle time. The factors were identified by statistical tools from Six Sigma and the result indicated that these factors were troublesome for the process. To improve these factors tools from both Lean and Six Sigma were applied. The tools revealed several issues that need to be improved in order to minimize the impact the factors have on the variation of the process. The tools have approached the issue from two different angles. Lean has focused on speed while Six Sigma has focused on reducing and removing the variation in the process. Together they have strengthened the maintenance process in terms of reduced cycle time and increased efficiency to mention some. The result of the Six Sigma project agrees with the main findings from the literature review, i.e. that the combination of these two methods is favorable and allows a process to be improved in several areas.

In addition this thesis has revealed through the Fishbone figure and VSM that more training of personnel with respect to the maintenance process could be advantageous and should be initiated. Since there is still potential to improve the process further with respect to the factor X_4, a 5S should be conducted to check if this tool would minimize or remove the impact from this factor. Also, closer collaboration both within and between the departments as well as an increased understanding of the whole process could contribute to less Silo-mentality and give more motivated personnel. This thesis also pointed out that the data stored in SAP for the RTD is incomplete and poorly structured however with minor improvements in SAP future Six Sigma projects can be more efficient. When the maintenance process has been stabilized and consider to be under control, further work for improving the process can be carried out.

The result shows that the combination of these methods is feasible and has proven to be favorable for improving the maintenance process. The methods complement each other by focusing on different areas which in turn gives an overall improved result. However, the result given here is not considered to be sufficient for stating that these two methods can be successfully combined regardless of the process to improve. More projects should be conducted on different processes at different companies to check if such successful combination would repeat itself. That being said, this thesis strongly believes that the combination is favorable and would recommend GE to evaluate such combination also in future projects.

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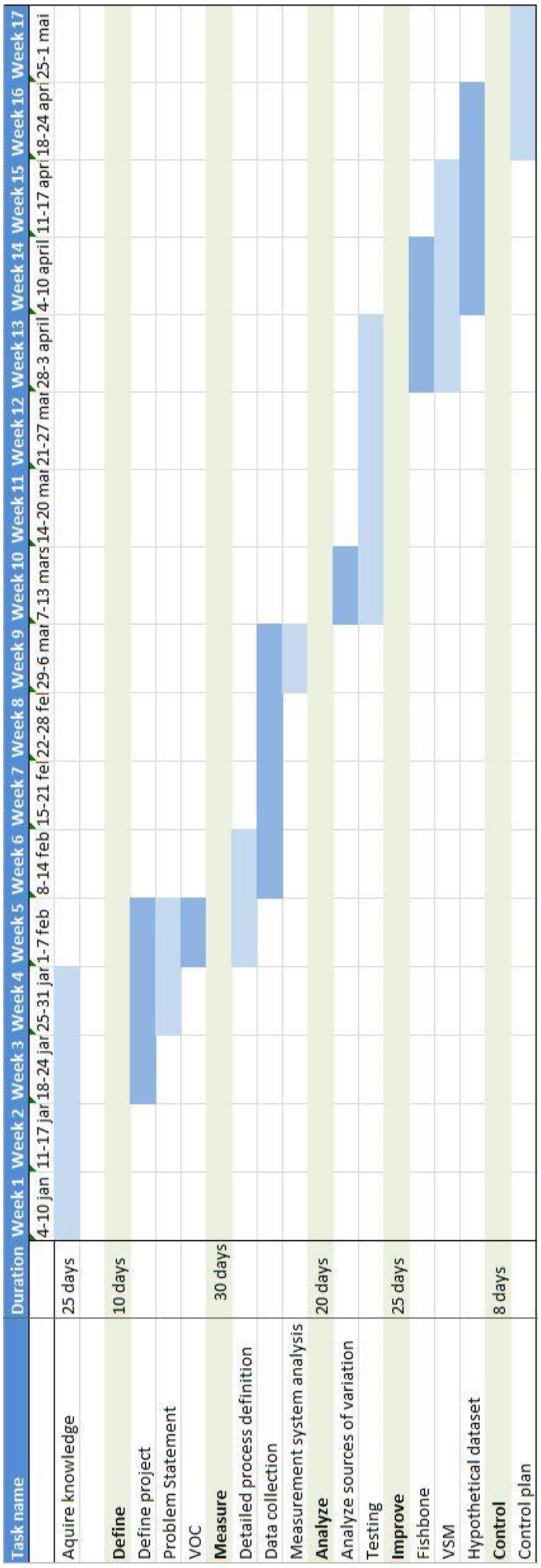
Attachments

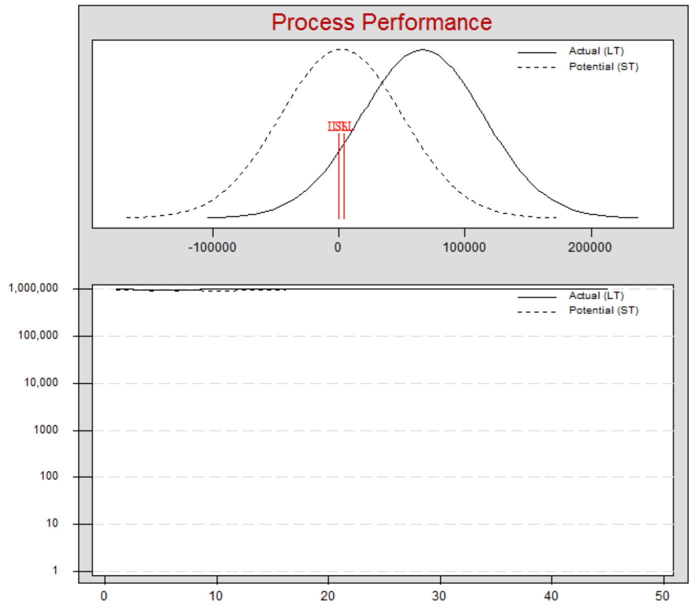
Attachment 1:

Gant diagram for the Six Sigma project



Attachment 2:

Process Performance and I and MR chart for refurbish every tool at a cost at 4100 kr.

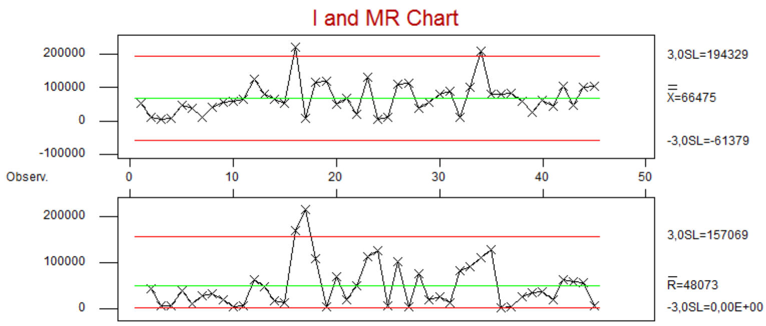


Process Demographics

Date:
Reported by:
Project:
Department:
Process:
Characteristic:
Units:
Upper Spec: 4100
Lower Spec: 0
Nominal:
Opportunity:

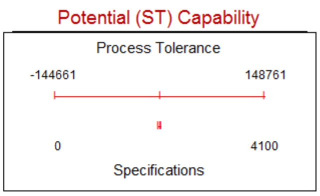
Process Benchmarks

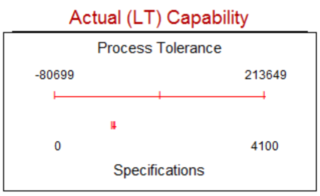
	Actual (LT)	Potential (ST)
Sigma (Z.Bench)	-2,20	-1,83
PPM	985979	966373



Capability Indices

	ST	LT
Mean	2050,0	66474,9
StDev	48626,5	48780,1
Z.USL	0,0	-1,3
Z.LSL	0,0	1,4
Z.Bench	-1,8	-2,2
Z.Shift	0,4	0,4
P.USL	0,483186	0,899498
P.LSL	0,483186	0,086481
P.Total	0,966373	0,985979
Yield	3,36273	1,40209
PPM	966373	985979
Cp	0,01	
Cpk	-0,43	
Pp		0,01
Ppk		-0,42

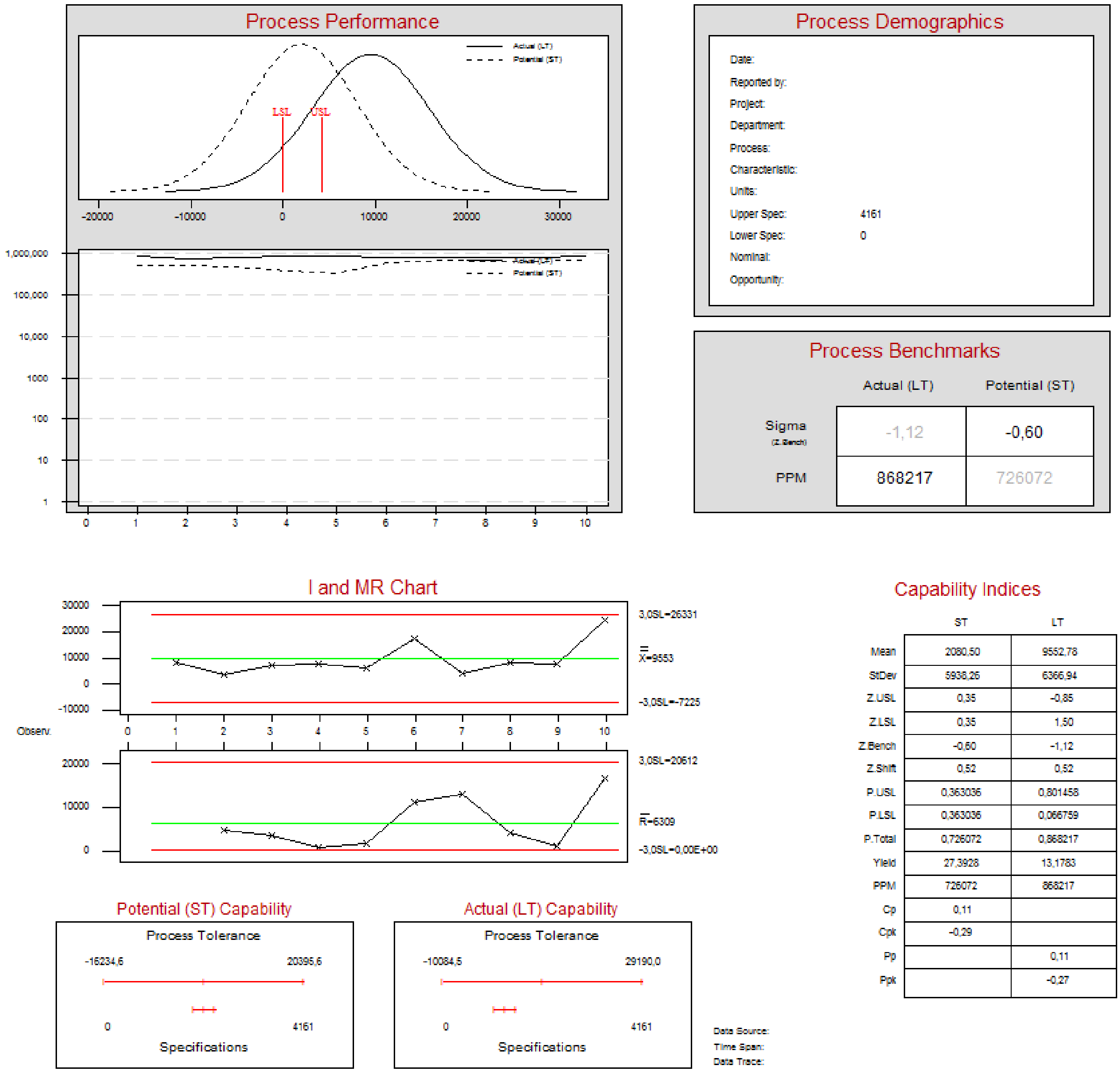




Data Source:
Time Span:
Data Trace:

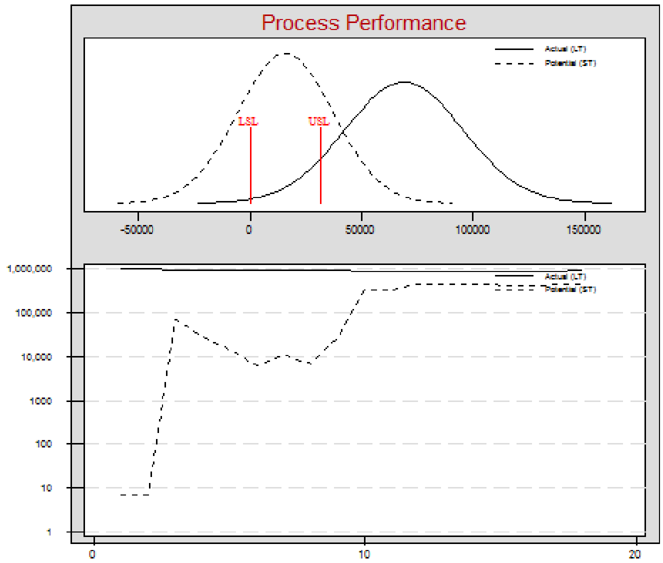
Attachment 3:

Process Performance and I and MR chart for refurbish every tool with a L1 for 4100 kr.



Attachment 4:

Process Performance and I and MR chart for refurbish every tool with a L2 for 31500 kr.

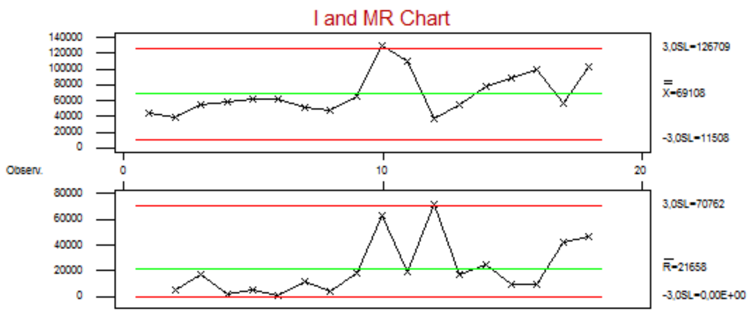


Process Demographics

Date:	
Reported by:	
Project:	
Department:	
Process:	
Characteristic:	
Units:	
Upper Spec:	31500
Lower Spec:	0
Nominal:	
Opportunity:	

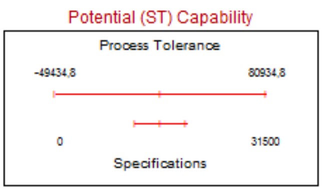
Process Benchmarks

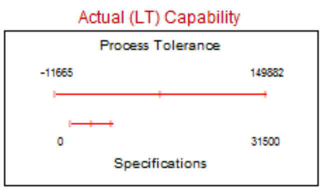
	Actual (LT)	Potential (ST)
Sigma (Z.Bench)	-1,45	0,10
PPM	926427	461979



Capability Indices

	ST	LT
Mean	15750,0	69108,5
StDev	21411,3	26531,8
Z.USL	0,7	-1,4
Z.LSL	0,7	2,6
Z.Bench	0,1	-1,4
Z.Shift	1,5	1,5
P.USL	0,230990	0,921830
P.LSL	0,230990	0,004597
P.Total	0,461979	0,926427
Yield	53,8021	7,35728
PPM	461979	926427
Cp	0,24	
Cpk	-0,58	
Pp		0,19
Ppk		-0,47

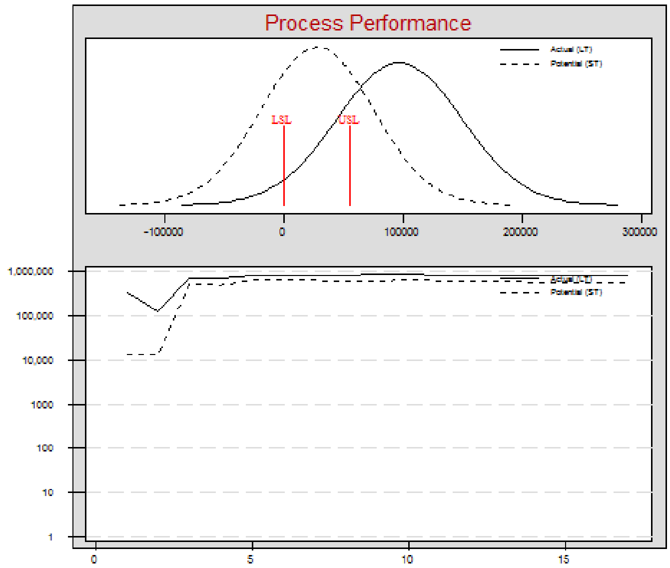




Data Source:
Time Span:
Data Trace:

Attachment 5:

Process Performance and I and MR chart for refurbish every tool with a L3 for 56000 kr.

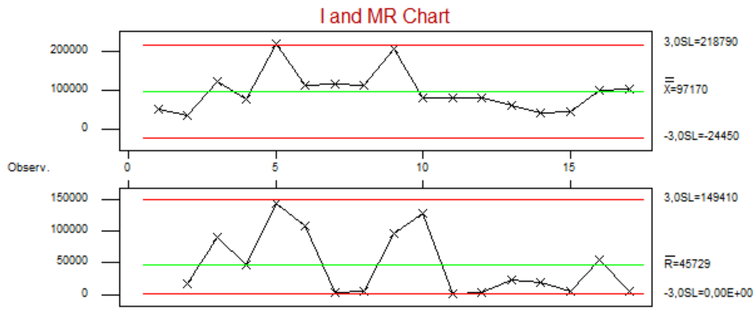


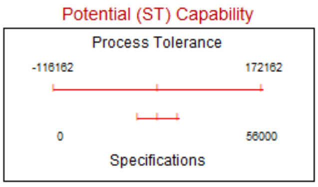
Process Demographics

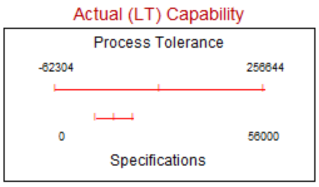
Date:
Reported by:
Project:
Department:
Process:
Characteristic:
Units:
Upper Spec: 56000
Lower Spec: 0
Nominal:
Opportunity:

Process Benchmarks

	Actual (LT)	Potential (ST)
Sigma (Z.Bench)	-0,90	-0,14
PPM	815939	553955







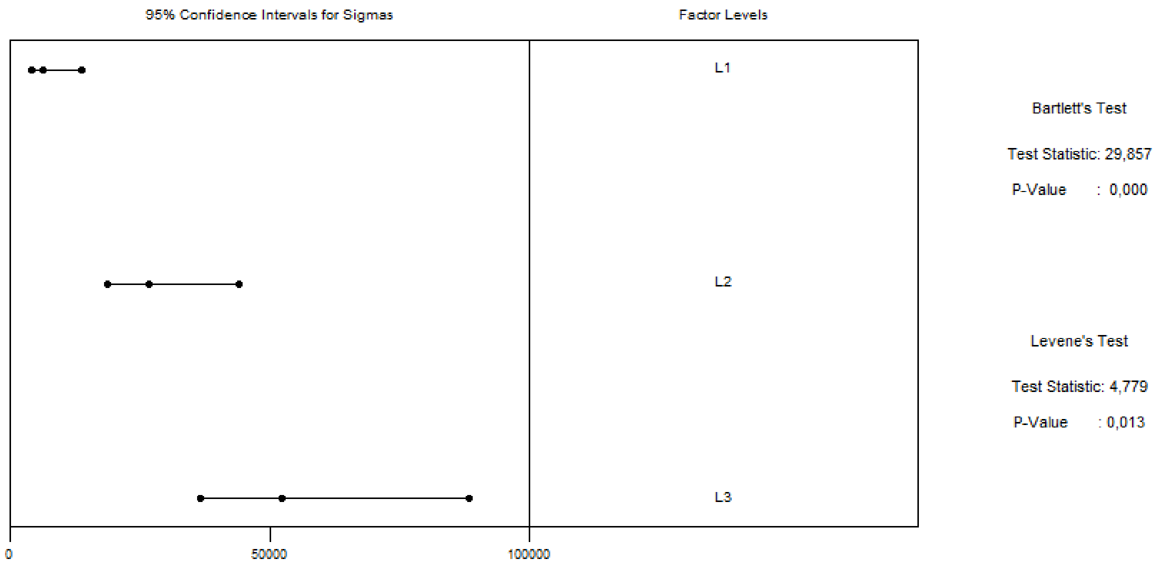
Data Source:
Time Span:
Data Trace:

Capability Indices

	ST	LT
Mean	28000,0	97170,0
StDev	47309,7	52334,7
Z.USL	0,6	-0,8
Z.LSL	0,6	1,9
Z.Bench	-0,1	-0,9
Z.Shift	0,8	0,8
P.USL	0,276977	0,784262
P.LSL	0,276977	0,031677
P.Total	0,553955	0,815939
Yield	44,6045	18,4061
PPM	553955	815939
Cp	0,19	
Cpk	-0,29	
Pp		0,18
Ppk		-0,26

Attachment 6:

HOV Levenes and Moods Median test on “Level of Maintenance”.



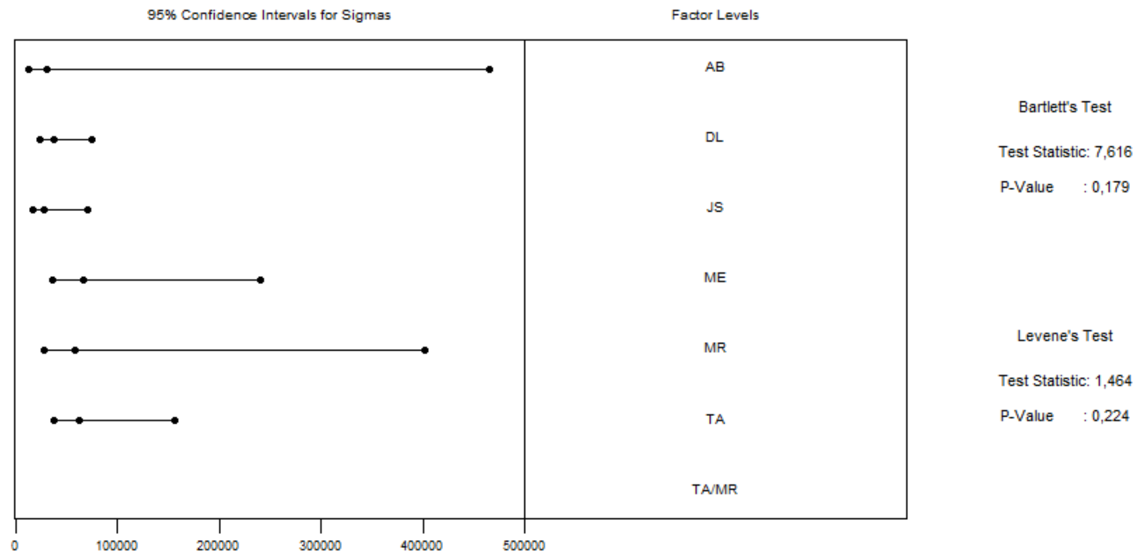

```
Chi-Square = 14,75    DF = 2    P = 0,001

                                          Individual 95,0% CIs
Level        N<=     N>    Median     Q3-Q1   ---------+---------+---------+-------
L1            10      0      7710      4953    (+)
L2             9      9     60099     40648                   (-+--------)
L3             4     13     80695     60192                     (------+----------)
                                              ---------+---------+---------+-------
                                                   30000     60000     90000

Overall median = 57751
```

Attachment 7:

HOV Levenes and Moods Median test on “Tool Coordinator”.




```
Chi-Square = 3,88   DF = 5   P = 0,566

                                        Individual 95,0% CIs
Tool-Coo    N<=    N>   Median   Q3-Q1  ----------+---------+---------+------
AB            2     1    51004   55818   (--------+-)
DL            6     7    62694   71739    (-----------+--)
JS            7     2    55700   23163         (---+)
ME            2     4    83713   98727           (-------+------------------)
MR            2     2    69314  105227   (------------+--------)
TA            4     5    78747   86456       (----------+--------)
TA/MR         0     1   103355  Not used
                                        ----------+---------+---------+------
                                              50000    100000    150000

Overall median = 57751
* NOTE * Levels with < 6 observations have confidence < 95,0%
```