



DEGREE PROJECT IN COMMUNICATION SYSTEMS, SECOND LEVEL
STOCKHOLM, SWEDEN 2015

Using Six Sigma Methodology to improve the performance of the Shipment Test

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2015-06-26

Master's Thesis

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Abstract

Competition and lead-time pressure motivates us to find new and better ways of continuously improving the output of our work. The emphasis on improvement in both efficiency and quality has become more and more significant in daily activities. The performance of Ericsson's AXE/APZ products during shipment test phase is one such activity and is the focus of this thesis project. One of the essential principles of shipment testing is to ensure that the test campaigns finish on time. Over the last several decades companies have spent large amounts of time and money on improving test quality and efficiency. Unfortunately, the results have not always been as good as expected. It seems that it is very difficult to improve shipment testing performance using traditional test management methods.

Motorola introduced Six Sigma in 1986 and achieved 5.4 Sigma level which help them saved 2.2 Billion dollars during the first six years. From Statistic aspect, it means only 3.4 defects per million opportunities. The Six Sigma methodology has been applied as a management philosophy focused on improving efficiency and performance during the shipment test period.

This thesis gives an introduction to the Six Sigma approach, including the concepts of Six Sigma, its history, development, and methodology. More specifically the author uses the Define, Measure, Analyze, Improve, and Control (DMAIC) approach to evaluate the performance of Ericsson's AXE/APZ Shipment Testing. This project goal was defined: Compare with the performance of 08AXE shipment test which 87% of test campaigns (2.68 sigma level) were finished on time, 3 sigma level in 09AXE shipment test which means 93%of the test campaigns will be finished on time has to be achieved. The thesis measured the 08AXE shipment test performance and analyzed the lead time of test campaigns, found the root causes such as poor documents quality from the legacy project, lack of test resources, no system impact analysis. The thesis also provided a set of proposals for improvements and control of the improved process in order to ensure sustainable improved performance results. Finally 93% test campaigns were finished on time in 09AXE and project goal was fulfilled.

Keywords

Six Sigma, quality, performance, AXE

Sammanfattning

Konkurrens och ledtid tryck motiverar oss att hitta nya och bättre vägar att kontinuerligt förbättra resultatet av vårt arbete. Betoningen av förbättring av både effektivitet och kvalitet har blivit allt mer signifikant i våra dagliga aktiviteter. Prestationen av Ericssons AXE/APZ produkter under sändningens test fas är en sådan aktivitet och det är där fokusen på detta tes projekt ligger. En av de grundläggande principerna av sändnings test är att se till att test kampanjer avslutat i tid. Under de senaste årtionden har företag spenderat stora summor tid och pengar att förbättra test kvalitet och effektivitet. Tyvärr har resultaten inte vart så bra som förväntat. Det ser ut så att det är mycket svårt att förbättra sändnings test prestationen när du använder traditionella test förvaltningsmetoder. Six Sigma metodik har blivit tillämpad som en ledningsfilosofi fokuserad på att förbättra effektivitet och prestation under test exekverings perioden.

Denna tes ger en introduktion till Six Sigma tillvägagångssättet, inklusive konceptet från Six Sigma, dess historia, utveckling och metodik. Mer specifikt använder vi Define, Measure, Analyze, Improve och Control (DMAIC) tillvägagångssätt för att utvärdera prestationen av Ericssons AXE/APZ sändnings testning. Denna process kräver definitionen av prestationsmålet, mätningar av nuvarande prestanda och analys av data för att hitta rötterna till orsakerna av problemen. Resultatet av denna definition, mätning och analys var en rad förslag till förbättringar och kontroll av den förbättrade processen för att säkerhetsställa hållbara förbättrade prestations resultat.

Nyckelord

Six Sigma, kvalitet, Prestanda, AXE

Acknowledgements

I appreciate the help of all the people at the PDU AXE I&V department at Ericsson AB in Älvsjö. These people helped me with their great kindness and patience. Bogumila Rutkowska, my supervisor at Ericsson, provided me with important and useful information about my thesis topic and other practical details at the company.

My greatest gratitude goes to Professor Gerald Q. Maguire Jr, one of the authorities with immense knowledge and experience in the area of communication systems for accepting to be my academic supervisor and examiner. His continuous guidance and encouragement help me to solve the difficulties in the thesis. I learned not only the knowledge, but also way of working and attitude towards the life. Thank you for your warm encouragement, helpful suggestions, and patience.

Preface

This thesis is part of the requirements for the examination for a Master Science in Engineering at Royal Institute of Technology (KTH). The project was performed at Ericsson AB PDU AXE Integration and Verification (I&V) Department from 15 Sep 2008- 31 March 2009. The examiner and supervisor of the thesis at KTH is Professor Gerald Q. Maguire Jr. at Department of Communication System. The supervisor at Ericsson AB was Bogumila Rutkowska.

This thesis tries to introduce the Six Sigma History and give explanation for Six Sigma from Statistic, Methodology and Philosophy Aspects. The thesis also demonstrates how to improve the quality and efficiency by applying Six Sigma in Shipment Test. It is one real business case to help the managers and testers to do some future research in the test process improvement.

The reason that this thesis is only being completed in 2015 is due to author's personal reason.

I really appreciate Bogumila to provide me a chance to do this research on Shipment Test, introduce and how to manage process; Also I will thank for Professor Gerald Q. Maguire Jr's encouragement, patience, and support.

Stockholm, June 2015
Yang Bin

Table of contents

Abstract	i
Keywords	i
Sammanfattning	iii
Nyckelord	iii
Acknowledgements	v
Preface	vii
Table of contents	ix
List of Figures	xi
List of Tables	xiii
List of acronyms and abbreviations	xv
1 Introduction	1
1.1 Background	1
1.2 Problem statement	1
1.3 Problem context	2
1.4 Selection of research methodology and philosophy	2
1.5 Structure of this thesis	3
2 Background	5
2.1 The History of Six Sigma	5
2.2 What is Six Sigma?	5
2.2.1 Six Sigma in terms of Statistics.....	6
2.2.2 Six sigma focuses on the Process	9
2.2.3 Six Sigma Methodology	12
2.2.4 Six Sigma Philosophy	14
2.3 Introducing Six Sigma to Shipment Test	14
3 Methodology	17
3.1 Research Process	17
3.2 Research Method	17
3.3 Define the project's goal	18
3.3.1 Test Process introduction	18
3.4 Measurements in Shipment Test Process	23
3.4.1 Original Test Data Collection	24
3.4.2 Current Process Performance	25
3.4.3 Current Performance using Six Sigma method.....	27
4 Analysis and Improvement	29
4.1 Data Analysis	29
4.1.1 Find Root Cause.....	29
4.1.2 Fishbone Diagram of root cause of Differ-Days	30
4.2 Suggested Improvements	32
4.2.1 Improvements in the Scope Collection Phase	32
4.2.2 Improvements in the Test Analysis Phase	32
4.2.3 Improvements in the Test Plan and Test Design phases	33
4.2.4 Improvements in the Test Execution phases	34
4.2.5 Improvements in Competence	34

5	Control of the improved process	37
5.1	Delayed delivery of the test requirements.....	37
5.2	Improve the quality of the delivery	37
5.3	Involve a tester in the whole set of test activities.....	37
5.4	Add System Impact Analysis before Test Analysis phase	38
5.5	Set up a “Knowledge Base”	38
5.6	Experience Sharing Activities	38
5.7	Result	38
6	Conclusions and Future work	41
6.1	Conclusions	41
6.2	Future work.....	41
6.3	Reflections	41
	References	43

List of Figures

Figure 2-1:	Normal Distribution [12].	7
Figure 2-2:	3 σ versus 6 σ	8
Figure 2-3:	Six Sigma focuses on the Process	10
Figure 2-4:	Unstable Process	10
Figure 2-5:	Six Sigma methodology focuses on the process [9]	11
Figure 2-6:	Stable Process	11
Figure 2-7:	Six Sigma Flow Chart	13
Figure 2-8:	Six sigma and Traditional Management in performance Improvement [9].	13
Figure 3-1:	Present Shipment Test Process	22
Figure 3-2:	Performance Measures	23
Figure 3-3:	Planned Days versus Actual Executed Days	25
Figure 3-4:	Differ-Days Distribution	26
Figure 3-5:	Differ-Days Distribution	26
Figure 3-6:	Current Performance using Six Sigma method	27
Figure 4-1:	Fishbone Diagram of root cause of Difer-Days	31
Figure 4-2:	Improved Shipment Test Process	33
Figure 5-1:	Differ Days Distribution 2009	39
Figure 5-2:	Improved Performances	40

List of Tables

Table 2-1:	The Motorola interpretation of the “Sigma” Standard (assuming a 1.5σ shift).....	8
Table 2-2:	Six Sigma Practical Meaning (Data from [14p. Slide 6])	9
Table 3-1:	A portion of the Original Test Data Collection.....	24
Table 4-1:	Test Result Analysis	29
Table 4-2:	Six main causes with sub causes Fishbone Diagram	31

List of acronyms and abbreviations

APZ	Control Part of AXE (CP central processor and RP regional processor)
AUP	part of APZ, system area module
AXE	Ericsson's Automatic Cross-Connection Equipment
BSC	Base Station Controller
CR	Change Request
DMADV	Define Measure Analyze Design Verify
DMAIC	Define Measure Analyze Improve Control
DPM	Defect Per Million
GE	General Electronic
GSM	Global System for Mobile communication
HLR	Home Location Register
I&V	Integration and Verification
KPIV	Key Process Input Variable
KPOV	Key Process Output Variable
LSL	Lower Specification Limit
LSV	Latest System version
MSC	Mobile Services Switching Centre
OT	One Track
PDU	Product development unit
PPM	Parts Per Million
R&D	research and development
T	Target
telecom	telecommunications
TR	Trouble Report
Sig	Signaling
ST	Shipment Test
STP	System Test Plant
USL	Upper Specification Limit

1 Introduction

This chapter describes the specific problem that this thesis addresses, the context of the problem, the goals of this thesis project, and outlines the structure of the thesis.

1.1 Background

Product development unit (PDU) Automatic Cross-Connection Equipment (AXE) is a platform organization in Ericsson which is responsible for the AXE system platform. The AXE is the platform for fixed telephony and cellular telephony (specifically the Global System for Mobile communication (GSM), Base Station Controller (BSC), Mobile Services Switching Centre (MSC), and Home Location Register (HLR), and their counterparts for third generation (3G) cellular networks) applications. PDU AXE management is located in Älvsjö, Sweden and has major operations in Italy and Croatia. AXE Integration and Verification (I&V) is also located in Älvsjö and provides the central and overall System I&V for the AXE platform. System I&V has overall responsibility for shipments of AXE products for both 2G and 3G cellular networks.

The AXE is continuously being developed by means of improvements based upon implementations using the most modern technology, both externally sourced as well as internally developed technology. Development is done component wise, thus there is a need to integrate and test all of these components together at the AXE system level. The PDU AXE management has made a decision that the quality of the system should be monitored from one central place -- in order to provide project and product management status of the entire system during the product's life cycle.

To remain competitive within an industry based upon the development of complex products and systems, there is a need for continuous improvement of quality in order to ensure that potential defects are detected as early as possible in the development process. The increasing demand for both efficiency and quality in product development requires best-in-class methods for measuring the relevant product development processes at an early stage.

During the year 2008 a new methodology for (AXE) Integration and Verification (I&V) was introduced – One Track (OT) [2, 3]. The AXE strategy team proposed shipment tests in three products areas: APZ (Control Part of AXE, CP central processor, and RP regional processor, IO input/output system), Signaling (Sig), and AUP (part of APZ, system area module). Each of these types of products use the same test processes. The test management team wants to improve the efficiency and performance during test execution.

An important factor in this improvement process is to find the key measurements for the performance of all elements of the product development process. The proposed process and tools for analyzing this product development process are based on the Six Sigma framework.

Six sigma has been widely known as a powerful statistic process control tool for improving the quality and a methodology for managing business from end to end. The thesis will show how to use Six Sigma methodology to improve the performance in shipment process, including: define the project goal--reduce the "Differ-Days" and reach to 3 sigma level in 09AXE shipment test, measurement current performance, analyze the data and find the root cause, provide improving proposals and control the improved process's performance to ensure sustainable results. Finally the project goal was fulfilled.

1.2 Problem statement

Integration and Verification (I&V) is a very important part in the test execution in telecommunications (telecom) industry. To a large degree, the quality of the product can be highly affected by the quality of test. However, in telecom industry, the quality of testing is not as high as expected. Since poor quality in the product will waste many resources and much money, improving

the quality of the product, especially the quality of testing of the product before it is delivered to the customer, is one of the most urgent issues which needs to be solved. The performance of Ericsson's AXE/APZ products [1] during the shipment test phase is the focus of this thesis project. Shipment test is the last test step before the product is delivered to the customer. In the Product development unit (PDU) Automatic Cross-Connection Equipment (AXE) I&V section, project managers are trying their best to find a reasonable way to improve the performance during shipment test execution. Six Sigma will be considered as an approach to improved this performance. This thesis will give an explicit explanation of the Six Sigma methodology, and use this methodology to solve the issue of providing high performance shipment testing.

1.3 Problem context

Shipment testing is the last stage of testing within the manufacturing process. Following this testing the product is shipped to a customer. Any problems that occur after the product has been shipped are much more expensive to resolve and they have a negative effect on the perception of the quality of the products produced by the manufacturer.

Shipment testing is an expensive process, since every day that a product spends in shipment testing is another day that the company has incurred the expenses for manufacturing the product but cannot receive payment for delivering the product. Since the products that this thesis is concerned with are Ericsson's high capacity telecommunications switches – generally deployed as public exchanges or used as infrastructure in macro cellular mobile networks – the large number of line and trunk interfaces means that a considerable amount of test equipment and infrastructure is required for shipment testing, since this equipment needs to be tested in a context comparable to what it will be expected to operate in.

Due to the high costs of testing and the even larger costs associated with **not** finding problems before the product is shipped, shipment testing performance can have a large effect (either positive or negative) on the company's profits. For these reasons this thesis project was formulated to enhance the performance of the shipment testing process. The expected outcomes are recommendations for improvements in this process that will reduce the number of systems under test and the time that these systems spend in testing. Reducing the number of systems under test will directly reduce the cost of the infrastructure required for this testing. Reducing the amount of time that each system spends in test will decrease the delay in delivering the products to customers (improving both cash flow and making the company's products more competitive due to reduced lead time and due to the customer experiencing fewer faults in the field).

One of the fastest growing areas within Ericsson is operation of telecommunication infrastructures for major customers. This means that Ericsson is paid by the customer to run the systems that have been delivered to the customer. For this reason, improving the quality of the systems delivered to the customer has a double effect, since in addition to the above benefits the company also reduces their own expenses in operating and maintaining the equipment after it has been installed in the field.

1.4 Selection of research methodology and philosophy

We selected the six sigma management methodology and philosophy because Six Sigma is both a methodology and a philosophy that improves quality by analyzing data with statistics to find the root cause of quality problems and to implement controls. Six Sigma applies a structured approach to managing improvement activities, which is represented by Define–Measure–Analyze–Improve–Control (DMAIC) used in process improvement or Define–Measure–Analyze–Design–Verify (DMADV) used in product/service design improvement [4]. In this project, DMAIC methodology will be implemented in the Shipment Testing Project.

1.5 Structure of this thesis

Chapter 1 gives a general introduction and describes the purpose of this thesis project, the issues to be solved, and the methodologies to be used. Chapter 2 describes the background of the PDU AXE I&V and the methodology of the Six Sigma about its history, development, and methodology. Chapter 3 defines the problem using Six Sigma methodology and describes the details of the measurement approach. Chapter 4 analyzes the data, collected from a database of measurements in order to find the reason for the problems found during shipment testing, and gives reasonable proposals for improvements. Chapter 5 describes how to control the process when implement the proposals and gives a summary of the results after the proposals have been implemented. Chapter 6 gives some conclusions , makes some suggestions for future work and short summary for reflection.

2 Background

In this chapter the history of Six Sigma will be presented. Additionally this chapter describes Six Sigma in different aspects: Statistics, Methodology and Philosophy. Section 2.3 the reason to introduce the Sigma in Shipment test.

2.1 The History of Six Sigma

The roots of Six Sigma as a measurement standard can be traced back to the early industrial era, during the eighteenth century in Europe; Carl Frederick Gauss (1777-1855) introduced the concept of normal curve [4p. 81]. The evolution of Six Sigma took one step ahead with Walter Shewhart showing how a three sigma deviation from the mean required a process correction [4p. 81, 5].

The evolution began in the late 1970s, when a Japanese firm took over a Motorola factory that manufactured television sets in the United States and the Japanese promptly set about making drastic changes to the way the factory operated [4p. 81, 6]. The Japanese changed the plant's operations and paid great attention to all of the manufacturing activities. With their scientific method and persistent efforts, in 1981, the yield could be controlled at approximately 95% (i.e., only 5% defects) which was much better than expected.

In 1981, a training institution in Motorola was established. They set a goal to improve the quality of their products by a factor of ten within 5 years [4p. 81]. Unfortunately, they did not achieve their target and their customers were not satisfied with the product quality. The company came to realize that that the poor product quality results from the accumulation of many little defects made during the manufacturing process – not inherent design flaws. Eliminating the source of those defects was therefore the only way the company could deliver higher quality to its customers [7]. At the same time, they decided that a standard measurement and control system for quality should be used to guide their manufacturing activities.

In 1985, Bill Smith coined the term “Six Sigma” [7]. In 1986, Motorola setup the Six Sigma methodology with the goal of improving quality [8] Motorola got the first Malcolm Baldrige National Quality Award from the U.S. Government in 1988 [9]. Motorola met their goals of 10-times improvement by 1989 and 100-times improvement by 1991. They achieved their 5.4 Sigma goal in 1992 and they saved US\$2.2 billion dollars during the previous six years [8].

In 1995, the Six Sigma methodology was spread to General Electronic (GE) by Jack Welch. At GE the results achieved over the first two years (1996-1998) were:

- Revenues had risen to \$100 billion, up 11%
- Earnings increased to \$9.3 billion, up 13%
- Earnings per share grew to \$2.80, up 14%
- Operating margin has risen to a record 16.7%
- Working capital turns rose sharply to 9.2%, up from 1997's record of 7.4 [10]

Today many well-known companies, such as GE, Ford, Honeywell, and Sony, have implemented Six Sigma.

2.2 What is Six Sigma?

Six Sigma is a well-proven customer satisfaction* and cost reduction improvement approach that has proved to be applicable in a variety of areas, such as: supply, manufacturing, design, finance, and marketing.

* Asea Brown Boveri is credited with emphasizing customer satisfaction as part of Six Sigma [4p. 82].

Motorola University defines Six Sigma as [9]:

- Six Sigma is a measurement scale upon which improvements can be gauged.
- Six Sigma is an overall methodology that provides standardized problem-solving tools.

The following subsection will address the six sigma in terms of statistics, methodology, and philosophy.

2.2.1 Six Sigma in terms of Statistics

Six sigma is a measurement tool for assessing the level of quality and is based on the Normal* distribution. In probability theory and statistics, the normal distribution is a continuous probability distribution that describes data that clusters around a mean or average. The graph of the associated probability density function is bell-shaped, with a peak at the mean. This probability density function is known as the bell curve. A normal distribution can be used to describe, at least approximately, any variable that tends to cluster around a mean [11].

Mathematically the normal (probability) distribution is characterized by the equation:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

In this equation μ (*mu*) is the arithmetic mean, i.e, simply the average of all of the observed values; σ (sigma) is the standard deviation, and σ^2 is the variance, thus a Normal distribution can be written as $N(\mu, \sigma^2)$.

Figure 2-1 shows a Normal Distribution. The probability under the curve is 1. The area under the curve and between the Lower Specification Limit (LSL) and Upper Specification Limit (USL) is called yield. This represents the fraction of observations whose value was acceptable. The area under the curve below LSL and greater than USL represent the fraction of defects, i.e., the defect rate. In the ideal state, the mean is equal to the Target (T).

* Also known as a Gaussian distribution.

Normal Distribution

Probability for the whole area under the curve = 1

Yield + Defective lower than LSL + Defective higher than USL = 1

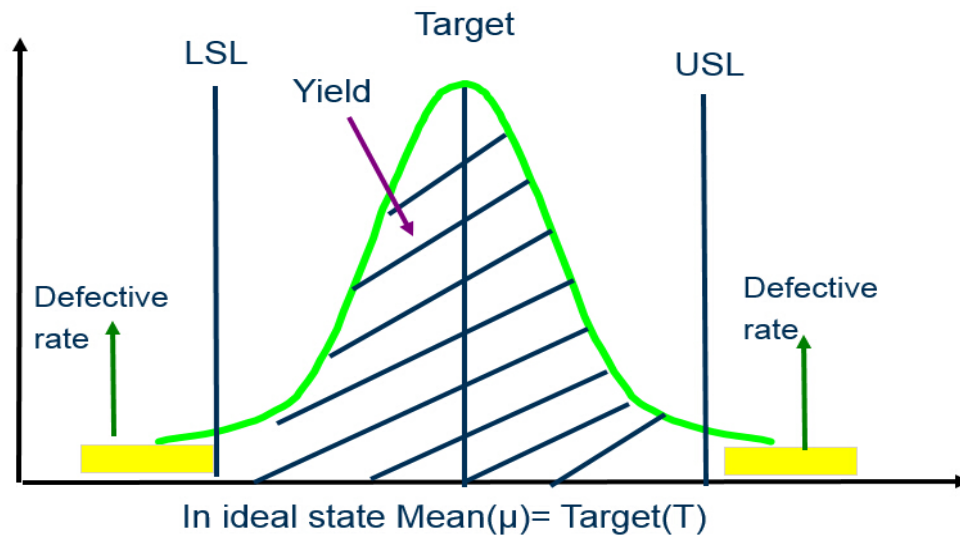


Figure 2-1: Normal Distribution [12].

2.2.1.1 The “Sigma” Standard

In statistical terms, Six Sigma quality means that for any given product or process quality measurement, there will be no more than 3.4 defects produced per 1,000,000 opportunities. An "opportunity" is defined as any chance for nonconformance or not meeting the required specifications [12].

Table 2-1 shows the “sigma” standard. From 2σ to 6σ , the improvement is obviously. The larger the number of sigmas, the lower the number of defects. Motorola assumes that the process has a 1.5σ shift (over time). Since the Six Sigma level has only 3.4 defects per million products, Motorola has called the Six Sigma standard “Zero Defects”.

Table 2-1: The Motorola interpretation of the “Sigma” Standard (assuming a 1.5σ shift)

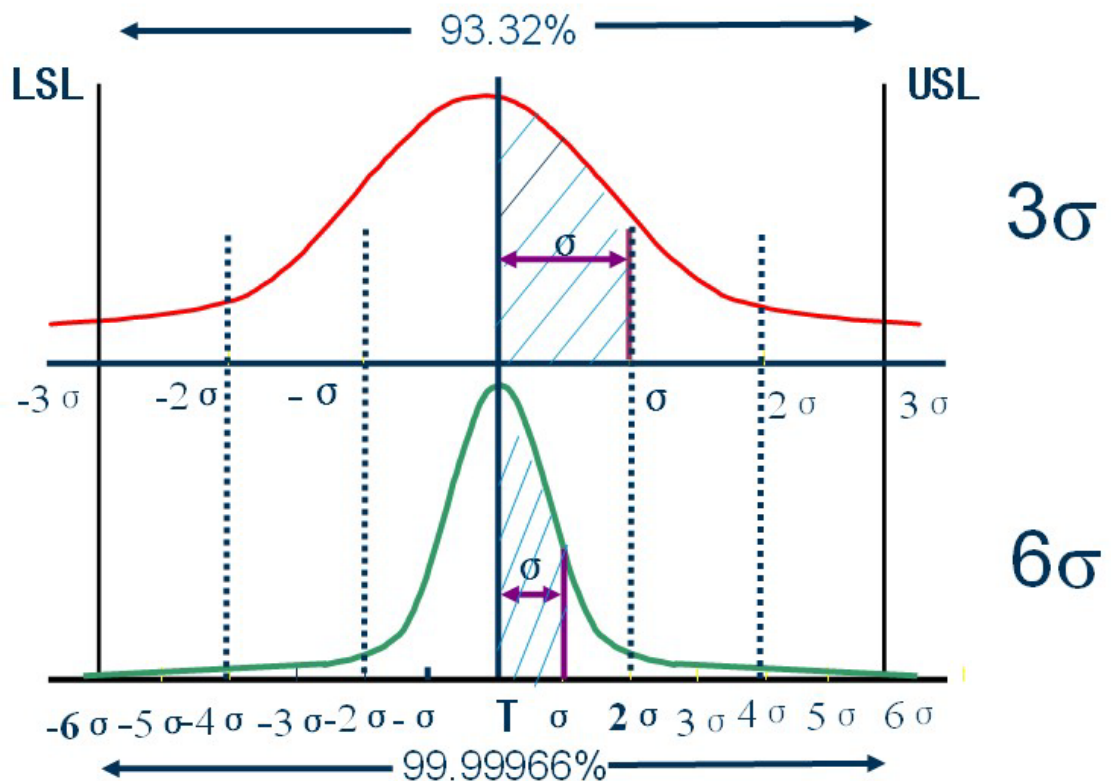
σ	Defects in parts per million (PPM)
2σ	308,537
3σ	66,807
4σ	6,210
5σ	233
6σ	3.4

Note that not all manufacturers assume a 1.5σ shift (over time), hence the table above needs to be adjusted to fit the expected actual long-term instability of the process [13].

2.2.1.2 3σ versus 6σ

Figure 2-2 shows a comparison between 3σ and 6σ . 3σ means ~93.3% of the products are good. While this sounds like very good performance, this level of quality would mean that there will be ~67000 mistakes or defects per million (DPM). This level of quality will lead to quite a lot of people being unhappy. In contrast when the manufacturer achieves Six Sigma this is a large improvement as there is a 99.99966% probability that the product does not have a defect. With this high level of quality there will be very few unhappy customers and this process will ensure a nearly perfect quality.

Note that in Figure 2-2 the scale between the LSL and USL for the two scenarios are the same, only the value of the “ σ ” of the two distributions are different. The process with a smaller value of the “ σ ”, will have the higher of yield. The challenge is trying to reduce the value of “ σ ”.

Figure 2-2: 3σ versus 6σ

2.2.1.3 Practical Meaning of Six Sigma

Does 99% yield of a process mean perfect performance? It maybe wonderful results for some scenario, but in reality, if most daily activities did not achieved Six Sigma, the world would be out of control.

Table 2-2 shows a comparison between 3.8 sigma and 6 sigma levels for a number of familiar activities. Although the 3.8 sigma level is very good outcome of a process, it is hard to image that the public would be happy if the United States Postal Service lost 54,000 letters *every* hour. At the Six Sigma level, the situation would be better controlled leading to only 7 letters being lost per hour. In this sense, the importance of achieving Six Sigma level is clear.

Table 2-2: Six Sigma Practical Meaning (Data from [14p. Slide 6])

Six Sigma Practical Meaning	
3.8 Sigma Level (99.73% goo)	6 Sigma Level (99.99966% good)
54,000 lost letters/hour	7 letter lost/hour
2 hours without telephone service/week	6 second without telephone service per 100 years
200,000 wrong drug perscriptions per year	68 wrong drug perscriptions per year
5,000 incorrect surgical operations/week	1.7 incorrect surgical operations/week
5 short or long landings at most major airports/week	One short or long landing every 5 years

2.2.2 Six sigma focuses on the Process

This subsections examines six sigma's focus on the **process** and how this provides the basis for the six sigma methodology.

2.2.2.1 All the activities can be considered as the processes

In daily life, all of your activities can be considered as processes. These activities need suppliers, customers, inputs and outputs, and a process. Here we will use a manufacturing process as an example. Figure 2-3 shows this manufacturing process as a module. The supplier and customer are the carriers of the module. Materials and tools are considered as two input factors. Operators, methods, machines, and environment are four elements that join in the process. Measurement Instruments and Criterion Inspection are used to check the Output. The relationships of all the elements in the process are illustrated in this figure. The output can be controlled by the various factors. If we do *not* control the process, then the result will be unstable and unpredictable.

Six Sigma consider the activity as Process

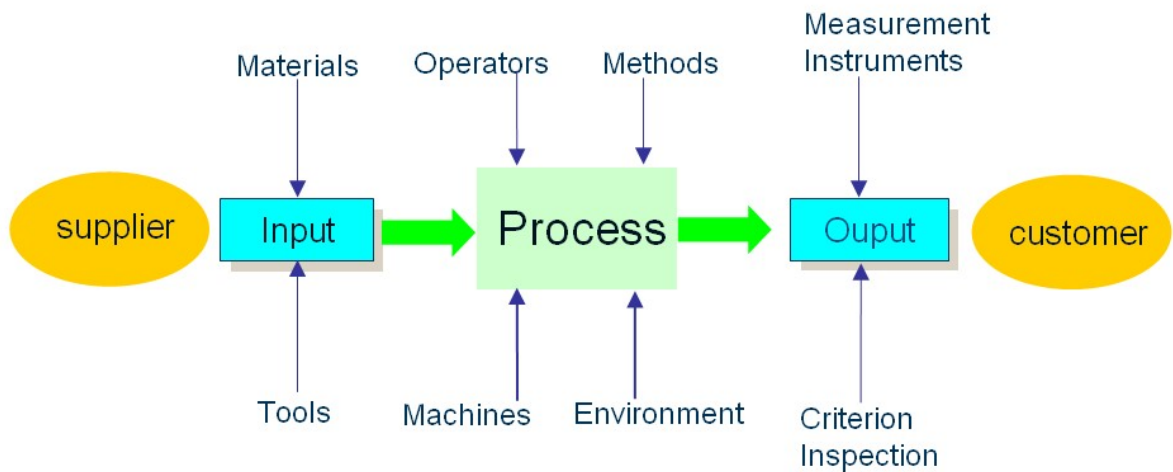


Figure 2-3: Six Sigma focuses on the Process

Figure 2-4 displays an unstable process. The process becomes out of control over time. It would be a disaster if this happened in manufacturing, as no one could predict the quality of the output of this process. Additionally, when the outputs are messy, it is either difficult or impossible to distinguish the relationships between variation causes and elements effect. Therefore, knowing the elements' effect and variation causes become the key to meeting the customers' expectation.

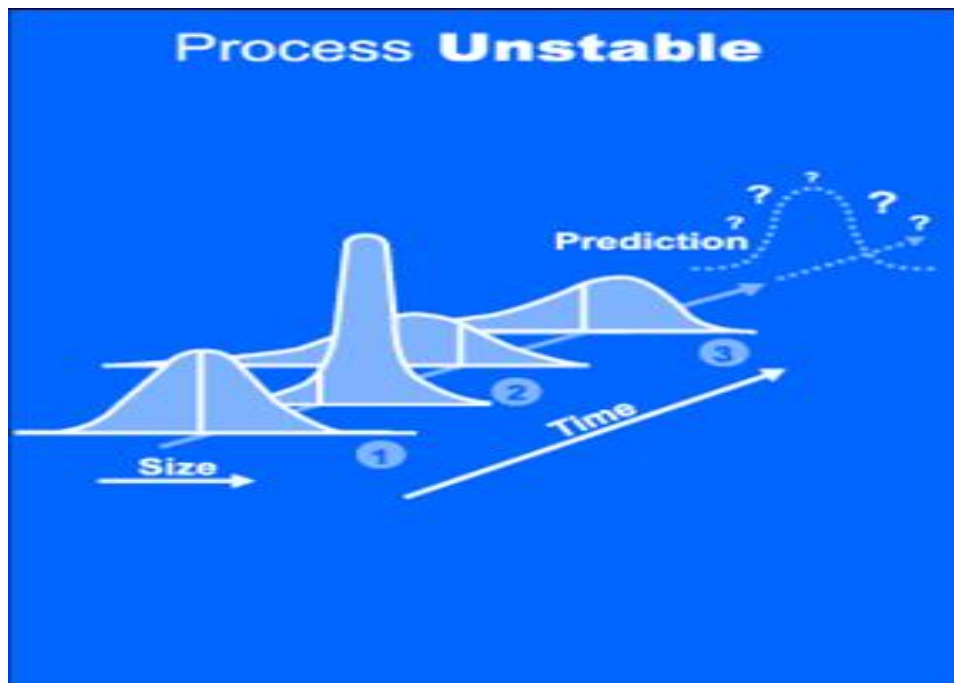
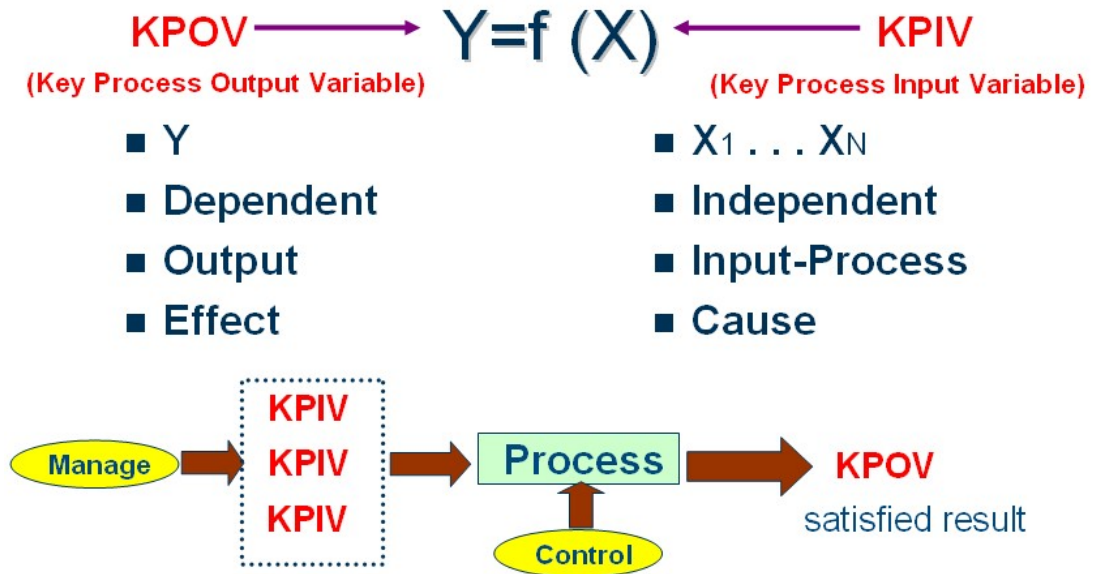


Figure 2-4: Unstable Process

2.2.2.2 Six sigma methodology focuses on the process

Figure 2-5 uses an abstract mathematic formula to show the relationship between Key Process Output variable (KPOV), Key Process Input Variable (KPIV), and Process. On the left side of the formula, Y stands for the output or effect. It is dependent on X. On the right side of the formula, X stands for an input or cause. Note that these X are independent of the process. F() stands for the process. If we manage the KPIV and control the process well, then a satisfactory result will follow.

Six sigma focuses on the Process



Manage the inputs, satisfactory outputs will follow!

Figure 2-5: Six Sigma methodology focuses on the process [9]

Figure 2-6 shows the case of a stable process. With good management and control, the process can be stable. If the process is stable, then the outputs follow the established distribution, hence we can predict what fraction of yield is good.

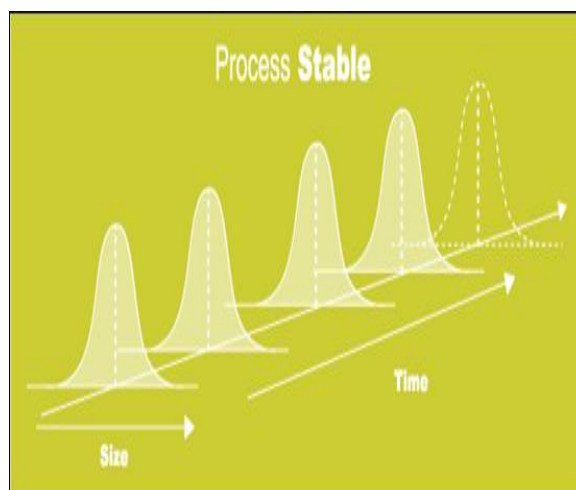


Figure 2-6: Stable Process

2.2.3 Six Sigma Methodology

Six Sigma is a methodology for inducing change or improvement into an organization using a group of tools to achieve and sustain results.

2.2.3.1 Six Sigma Methodology

Six Sigma includes two different methodologies[14]:

DMADV (Define Measure Analyze Design Verify) A methodology that achieves Six Sigma performance for new processes. It can also be used to make radical improvements.

DMAIC (Define Measure Analyze Improve Control) A methodology targeting existing processes for making incremental improvements.

The DMADV Model [9] consists of:

Define	Define the project goals and customer deliverables.
Measure	Measure and determine customer needs and specifications
Analyze	Analyze whether the process options meet customer needs or not.
Design	Design new process to meet customer need
Verify	Verify the design performance and ability to meet customer needs.

DMADV is an innovation driven methodology for a new process.

The DMAIC Model [9] consists of:

Define	Define the project goals and customer deliverables, set up schedule.
Measure	Measure the process to determine current performance
Analyze	Analyze and determine the root causes of the defects
Improve	Improve the process by permanently eliminating the defects.
Control	Control the improved process performance to ensure sustainable results.

DMAIC is use to improve quality and reduce variation in an existing process.

2.2.3.2 Six Sigma Flow Chart

Figure 2-7 shows the Six Sigma flow chart. Initially one defines the project’s goals and customer deliverables. Whether it is new process or not determines which methodology should be chosen: DMADV or DMAIC. If it is a new process or new product, then the next step is to develop measurement criteria; and then analyze process options to see whether the outputs meet the customer’s requirements or not. After that, a new process is designed and the performance verified. Otherwise, for an existing process or product, the second step is to measure the current performance and decide whether a new design is need or not. If it a new design is needed, then go to the DMADV Analyze step. Otherwise, analyze the current performance and try to find the root causes for the observed outputs. Finally, improve the process and control the process performance to ensure sustainable results.

Six Sigma Flow Chart

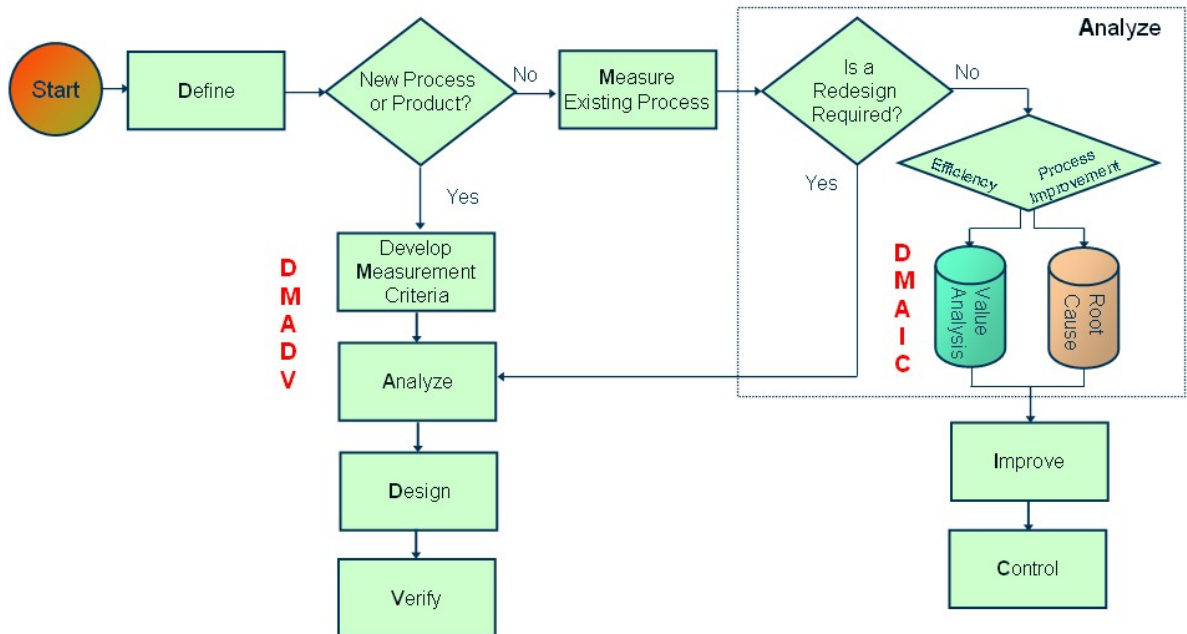


Figure 2-7: Six Sigma Flow Chart

2.2.3.3 Six sigma and Traditional Management

What can we expect from Six Sigma? With Six Sigma, the performance should have a prominent improvement. For example, Figure 2-8 shows Six Sigma and Traditional Management with regard to performance improvement over the long term. The Y-axis indicates Performance Improvement and the X-axis is time.

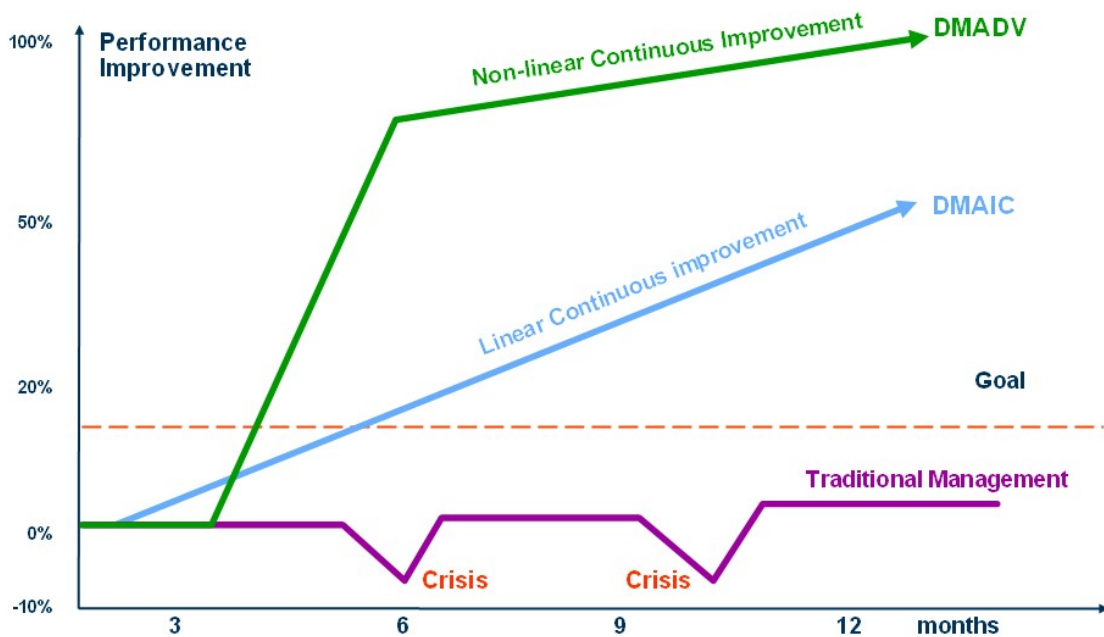


Figure 2-8: Six sigma and Traditional Management in performance Improvement [9]

Since traditional management did *not* develop a new process or improve the quality of a process, there is little or no performance improvement. When a crisis occurs, the performance will go down. After the crisis, the performance will recover and there may be limited improvement. When another crisis occurs, the same thing will happen again. Following this method, it is very difficult to improve performance.

For the DMAIC, initially time will be spent evaluating the existing process, and then time will be spent to try to find the root causes of problem. As each of the root problems is addressed there will be nearly linear continuous improvement.

For the DMADV, a longer time will be spent evaluating the existing process compared with the other two approaches as time must also be spent on developing the new process. Introducing this new process will result a non-linear continuous improvement. The performance improvement using this method is the largest of the three alternatives.

2.2.4 Six Sigma Philosophy

Six Sigma is a kind of customer focused culture. This philosophy can drive remarkable improvement in a business with sustainable consequences and improve the customers' satisfaction. The reason for this improvement is that a Six Sigma program provides [9]:

- Rapid, breakthrough performance,
- A continuous improvement program,
- Effective goals and metrics, and
- A standard problem solving methodology.

2.3 Introducing Six Sigma to Shipment Test

Shipment test is one of the most important processes in the whole series of test activities. As described in Section 1.3, the quality and efficiency of shipment test are very important. Most shipment test activities are executed in an environment comparable to the customer's environment, i.e., the background activities and traffic used for test are based on the customer's traffic model(s).

According to Ericsson's internal documentation, the purpose of the shipment test is to [15]:

- Ensure that the system is compliant with the system requirements of robustness, load/stress, recovery, operational stability, accuracy, characteristics, compatibility, node interoperability, maintainability, and security.
- Ensure that the system is compliant with legacy requirements.
- Ensure that the shipment is ready for deployment by verification that the system is updated and that the system upgrade instructions will work correctly in a customer-like environment.

Above purposes that the shipment test concerns both the hardware & software *and* the documentation that accompanies the delivered system. We can also see it is important that the system work with the customer's existing infrastructure and that it works with the latest hardware & software updates (specifically those updates released to customers).

In a shipment test, the test process is divided into **test campaigns**. Each test campaign includes many **test cases**. These test cases are designed to cover the system's requirements.

Ensuring that the test campaigns finish on time is a very important aspect when evaluating the performance of the testing process. Delays, i.e., a test campaign finishing at a date later than the planned deadline, can increase cost. While finishing testing much earlier than deadline will waste resources and indicates poor planning. The delay days and finish early days are called differ-days, as each represents a difference from the planned test campaign duration. Reducing the number of differ-days can reduce the cost of testing and will improve the efficiency of the shipment test process.

This thesis project used six sigma theory to define the project's goal, to measure the current shipment test process' performance, analyze the data, find solutions, and suggest proposal for improvements; and finally implement the proposals in the real test activities.

3 Methodology

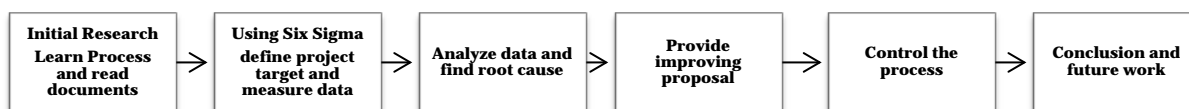
This section presents the Research Process and Research Method. Additionally, define the project goal in the shipment test and how to measure the performance are also be stated.

3.1 Research Process

The research process started with discussion between the industrial adviser Bogumila and me about the possibility to implement Six Sigma methodology in Shipment Test. Then she decided to assign me as an internal process consultant do some research on current process in Shipment Test and try to find solution to improve the quality and efficiency. She also helped me to apply for a temporary ID and password so that I could login in the internal network and find all the relative database and documents.

Learned two weeks about Test Process and got the all the finished data of 08AXE Shipment Test, started to use Six Sigma methodology to define and measure the data. A questionnaire which was made to try to collect the difficulties during the test activities could be a good way to find root cause. Private interviews with all the testers in the section helped me to generate some ideas for improvement proposals. With Bogumila's support, the improved proposals were implemented in the section and Project Managers were the role who were controlled the improved process's performance to ensure sustainable results.

Below is the overall work flow of this project:



3.2 Research Method

Both quantitative research method and qualitative research method were used as complement to achieved the project's goals [16].

Quantitative Research Method	The reason for chosen Quantitative Research method since it supports experiments and testing by measuring variables to verify theories and hypothesis[16]. The 08AXE "Differ-Days" which is collected from the database and considered as the hypothesis by Six Sigma in this project is measureable with quantifications.
Qualitative Research Method	The reason for chosen Qualitative Research method since it concerns understanding meanings, opinions and behaviors to reach tentative hypotheses and theories [16]. "Add one more process System Impact Analysis before Test Analysis phase" which is one of the improvement proposal to reduce the risk of re-plan is developed by understanding the process meaning and testers' behaviors.
Deductive approach	This research approach is used to verify or falsify hypotheses [16]. 46% of the test cases which were using automated test tools in 08AXE shipment test are summarized. In this case, develop more auto test tools by Test Designers is the deductive result.
Surveys	It is a descriptive research method, which examines the frequency and relationships between variables and describes phenomenon that are not directly observed. Cross-sectional surveys collect information on a population, at a single point of time. Due to surveys' characteristics and using questionnaires, the method can be used

with quantitative and qualitative methods. [16]. A questionnaire was made to try to collect the difficulties of testers during the test activities.

3.3 Define the project's goal

The PDU AXE I&V section finished 74 Test Campaigns in 2008. Of these 64 of them (87%) finished on time according the standard shipment test plan. While this result is actually acceptable, it is at the 2.68σ level, hence there was plenty of room for improvement. A goal of the 2009 AXE shipment test project* was to ensure that the test campaigns could be finished on time 93% of the time, which corresponds to a 3σ level.

In this project, we define differ-days as the Key Process Output Variable (KPOV), while the Key Process Input Variables (KPIVs) are lead time, test environment, test tools, and human resources. The performances measure will be the percentage of test campaigns that finish on time.

3.3.1 Test Process introduction

There are five main steps in the existing shipment test process: test analysis, test plan, test design, test execution, and test report. Each of these steps is explain in further detail below:

Test Analysis	Test analysis is performed in the test analysis activity during the project planning phase by the test leader and test experts. The outcome of the test analysis is documented in a test analysis report, which may be thought of as a technical report providing the basis for test planning.[15]
Test Plan	The test plan is produced in the test planning activity during the project planning phase. The test plan can be updated at any time during the execution phase of a project[15].
Test Design	Test design is completed before the project execution phase. In this step, the test structures are created and updated, test cases map the requirements to specific tests, and test tools are developed and maintained.
Test Execution	Test execution includes test case execution and trouble shooting. In this phase, test cases are executed, test results are registered, and test case scripts and manual test instructions are updated.
Test Report	The test report approves the test results, documents the test cases that were updated during the test execution, documents the test scripts that were updated during the test execution; records test activities, test tools and test structures, and the results of the individual test cases are stored in log files.

Besides the five main steps, the following steps were introduced:

Core Scope	The core scope describes the main purpose of the test, system requirements, and main test activities. The project manager and test leader define the test's core scope.
Change Request	A change request indicates that a requirement is changed. Such a change request can occur before or during the test activities. Since the introduction of a change request will reduce the efficiency of the test activities and increase the cost of testing, it is important to try to minimize the number of the change requests.

* This master's thesis project was formulated to help the company to realize this goal.

Project Management	The project management is a team including the project manager, test leader, and project planner. This team is responsible for the test result, planning, organizing, and control the project.
Implementation Proposal	The implementation proposal describes how the test requirements will be met and the tests performed. The proposal consists of an abbreviated introduction to the major tasks in the test implementation, the overall resources needed to support the execution effort (such as hardware, software, tools, materials, and personnel). The implementation proposal is developed during the test planning phases and is updated during the test design phase; the final version is provided to the test execution phase.
Trouble Report	A trouble report is used to detection, report, resolve, and track test issues during the test execution. This report will be sent to the test designer.
Test Result	The test results include the information about each of the test case results (pass or fail), the testers who performed each test, and the date of each test.
Designers	Designers are members of test teams who participate in the test design activity and deal with trouble reports.
Correction	Correction is the process of integration and regression test. This process is carried out to ensure the quality of the system to be delivered. The correction of faults must (in most cases) have a higher priority than testing new functionalities. Additionally, the trouble report (TR) backlog should be empty or as small as practically possible.
Next LSV	The Latest System Version (LSV) is regression testing of the latest system version *. The quality should be sufficient for system verification [2]. The corrected test cases will be used in the Next LSV.

3.3.1.1 Roles in Shipment Test Process

The roles of those persons participating in shipment test process are described in detail below. Several persons may share one role, or have the same role (usually within different test activities). A person may also have more than one role.

I&V Project Manager	The I&V Project Manager Controls the whole process and is the driver of the project in which one or several instances of this process are executing. The I&V Project Manager does not actively take part in this process, but is the receiver of progress reports and test reports and assists the test leader with planning.
Assignment Owner	The assignment owner has the similar purpose as the project manager, but assigns the verification goals to a project manager and is steered by the assignment handling board.
Test Leader	The test leader is the driver of the shipment test process. The test leader is assigned to lead one or more test activity teams and reports to the I&V Project Manager. Test leaders take part in all

* In the case of the AXE a version consists of specific releases of both the hardware and software.

activities (test analysis, test planning, test design, test execution and test reporting).

Tester	Testers are members of test activity teams and participate in the test design, test execution, and test reporting activities.
Test Script Designer	The test script designers are members of test teams and participate in the test design and correction activity.
Tool Developer	Tool developers develop and maintain I&V test tools.
Test Expert	Test experts participate in all activities and provide expert skills with regards to methods, tools, and the products tested.

3.3.1.2 Existing Shipment Test Process

Figure 3-1 shows the existing shipment test process (as it was before the start of this thesis project). Additional details of this process are given below:

1. The project management team begins by collect the core scope from research and development (R&D) projects. This scope contains new project verification requirements, legacy requirements from the last LSV, and some Delta test campaigns which are unsolved test cases (failed parts of earlier trouble reports) from the last LSV. Additionally, change requests may also come to the project management during any phase of the test activities. The I&V project manager, test leaders, and test experts analyze all approved requirements and change requests (there is no standard for deciding which change request has higher priority, hence which change requests are adopted depends on the actual test resources which are available) and decide which of them should be verified in the different test activities.
2. After deciding upon the test scope, the test leader will output an implementation proposal which describes how the test requirements will be performed. The proposal contains a short introduction to the major tasks in the test implementation, the overall resources needed to support the test execution effort (such as hardware, software, tools, materials, and personnel). If the assignment owner approves the implementation proposal then it is allocated to the test leaders.
3. An initial test analysis is generated by the test leader and test experts. A subsequent test analysis may be performed at any time during the execution phase of a project (typically triggered by the reception of change requests or for any other reason). The initial test analysis includes the following tasks, summarized in a test analysis report:
 - Define a baseline (all detailed requirements and high level design documents),
 - Configure projects and test items, specify users and user rights in project management tools,
 - Specify requirements that are planned to be verified in the different test activities,
 - Specify test plant configuration and required new hardware,
 - Specify test tools baseline (software),
 - Establish test environment specification, and
 - Specify external test tools (if needed).

If the test analysis report is approved by the I&V project manager, then the process moves to the test plan phase, otherwise the report is returned to project management for a redesign.

4. An initial test plan is generated by the test leader and test experts. A subsequent test plan may be generated at any time during the execution phase of a project (as noted previous it may be triggered by the reception of change requests or for any other reasons). The initial test plan includes the following tasks, summarized in a test plan report:
 - Define organizations, roles, test objects (platforms and LSVs), and test activities,
 - Book time schedule, resources, and test plant (including both testers and test equipment),
 - Specify trouble report handling guidelines,
 - Specify dependencies on other projects,
 - Prepare risk analysis,
 - Prepare schedules for execution of test cases (generating a progress graph),
 - Specify test tools and training needs, and
 - Specification of test activity progress reporting methods and documentation rules.

If the test resources, time plan, and test plant are ready, then the process moves to the test design phase otherwise the project management needs to coordinate the resources and test plant.

5. The test design includes the following tasks:
 - Create and update the test structures,
 - Map the requirements to test cases,
 - Design and update automated test case scripts that should be verified by simulation,
 - Configure the test environment (when feasible), and
 - Release the test tools to the testers.

If the test structures, test cases, and test tools ready, then move to the test execution phase; otherwise the project management needs to coordinate the test structures and test cases.

6. Test execution includes the following tasks:
 - Execute each of the test cases ,
 - Register (i.e. store and report) the test case results,
 - Generate trouble reports regarding the products,
 - Generate trouble reports on tools,
 - Generate the test report, and
 - Update the test case scripts and manual test instructions.

The test execution will output test results and trouble reports. The test results contain information of the test case results (pass or fail), testers, and test date. If the test cases were passed then the process will move to the test report phase. If failures occurred during the test execution phase, i.e., test cases were not passed, some test scripts could not be successfully completed, or bugs were found, then the testers will register a trouble report in the system and sent to the designers. The designers will handle trouble reports as soon as possible.

7. The first quality check is done by the design teams doing basic tests on a component level in the design environment. However, the quality of the system will not yet be sufficiently secured for system verification. For this reason a number of additional quality checks is done. The final stage of quality checks is the shipment test.

When the Designer receives a trouble reports, they will try to establish the source of the problem as soon as possible and then the process moves to correction which means that there will be an integration and regression test of the proposed correction. If the failure is not serious, then after the test cases are passed in the integration and regression test, the trouble report will be marked resolved and sent back to the test team for further test execution.

If the failures are considered serious, then to ensure that the test scope is finished on time, this trouble report will be handled in the next LSV. This implies that if the failure is related to new functionality that this functionality will *not* be included in this release. If the failure is in the baseline functionality, then the system will not be shipped until the problem is resolved.

8. The test reporting phase includes the following tasks:

- Approve test case results,
- Approve test cases that were updated during test execution,
- Approve test case scripts that were updated during test execution,
- Report the testing progress,
- Prepare test activity reports,
- Store log files,
- Finish the baseline of test tools,
- Finish the baseline of legacy test structures,
- Test report (including or referencing),
- Evaluate process performance, and
- Initiate root cause analysis of stopping TRs* registered during the shipment test.

The test leader will check the test report results to see whether they match the test criterion or not. If the test report passed, then the process moves to the AXE release phase; otherwise the Project Management must analyze the test report and try to find the root cause of the identified problems.

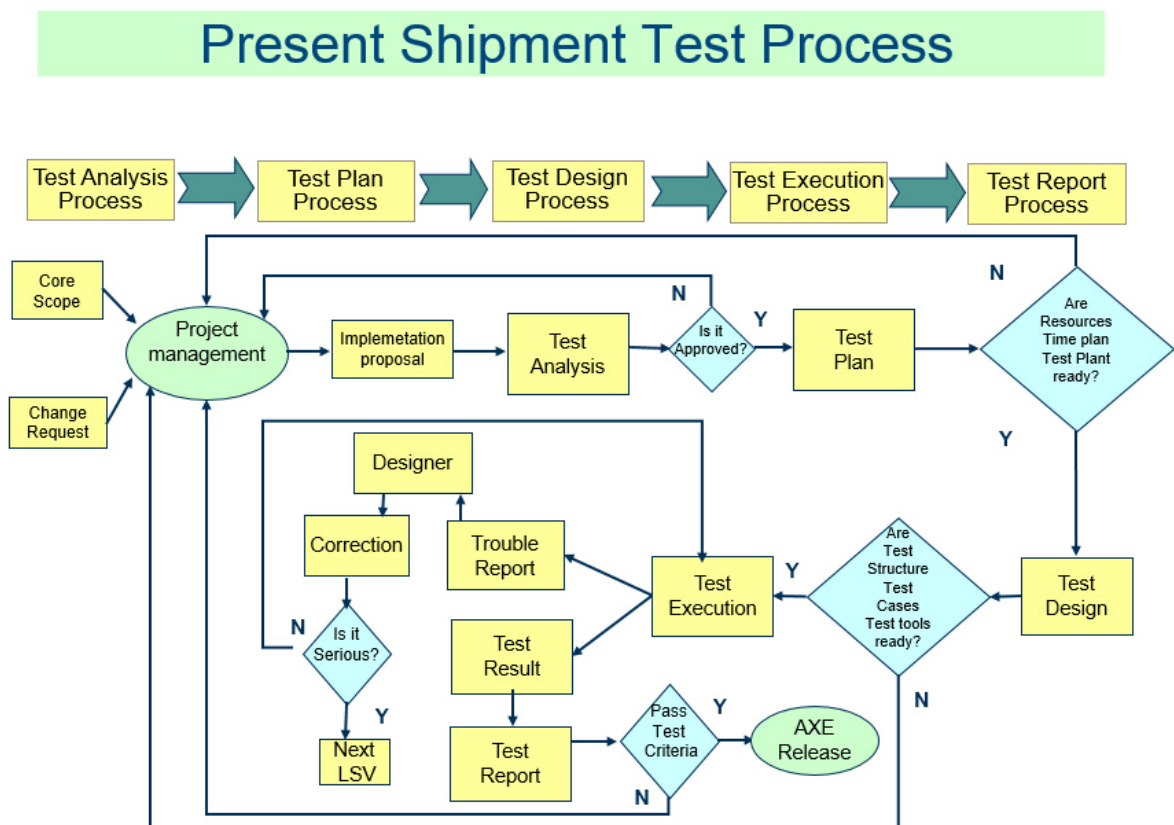


Figure 3-1: Present Shipment Test Process

* A stopping trouble report is a trouble report that failed test cases could not be solved..

3.4 Measurements in Shipment Test Process

Figure 3-2 shows the relationship between input and output performance from a mathematical perspective.

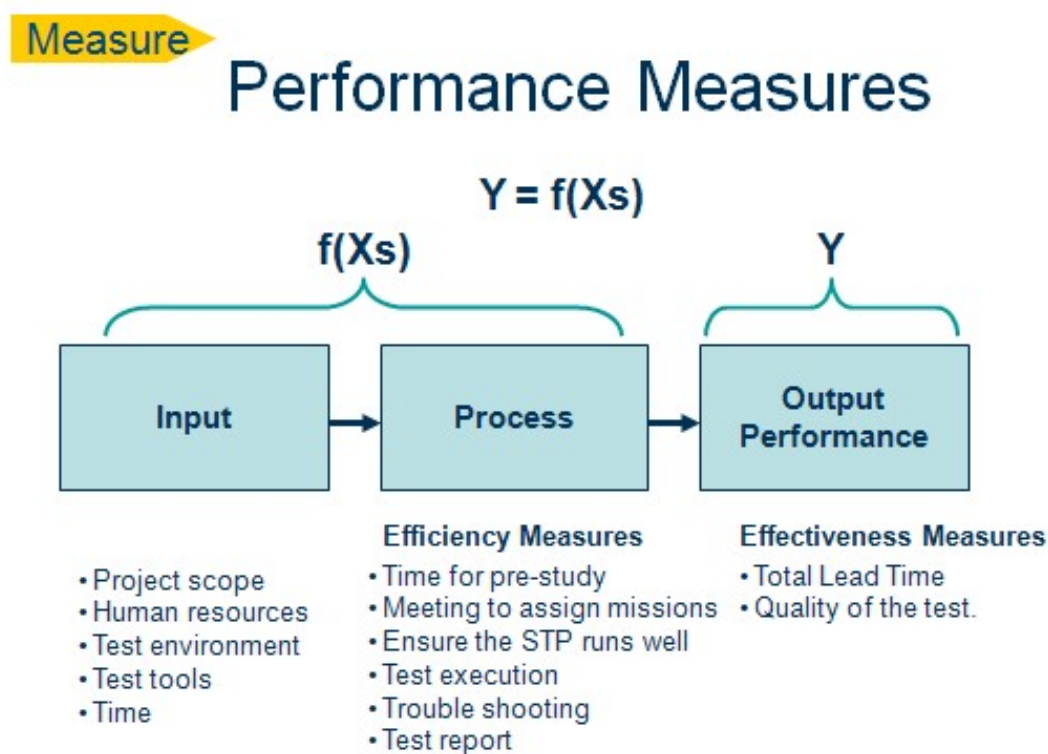


Figure 3-2: Performance Measures

The “Xs” stands for the inputs which include project scope, human resources, test environment, test tools, and time. The “f()” represents the process, which includes the *efficiency measures* (such as the time required for the pre-study, meetings to assign missions, ensuring that the system test plant (STP) runs well, test execution, troubleshooting, and generation of the test report). The “Y” means the output performance which is the *effectiveness measures*. In the Shipment Test process, the baseline is *total lead time* and *quality of the test*.

In order to understand the measurements, we define three important terms:

Planned Days	Planned days is the planned number of days from the beginning of the test analysis process to the end of test report process.
Actual Executed Days	Actually executed days is the number of days from the beginning of the test analysis process to the end of test report process.
Differ-Days	Actual Execute Days- Planned Days

The target of the measurement is the measure: **Differ-Days**.

3.4.1 Original Test Data Collection

Table 3-1 is part of the collected Original Test Data Table. In this table both **Planned Days** and **Actual Executed Days** are shown, then **Differ-Days** is calculated from these values.

If the value of **Differ- Days** was “0”, it means the Actual Execute Days equal to Planned Days. The management makes perfect planning job. In the real test activities, “Differ-Days” is very hard to achieve “0” due to many reasons:

- Delivery delays and poor quality of the deliverables from other departments) occupied lots of lead time to understand
- In order to ensure the test environment runs well proper configuration of the STP (System Test Plant) is necessary, however configuring STP is time consuming.
- Trouble shooting takes a lot of time during the test execution and
- Only 46% of the test cases were using automated test tools. Too much manually test and it is hard to evaluate the execution time.
- Other reasons, abnormal case, lack of Human resources.....

If the “Differ-Days” can be in the acceptable range, it also can be considered on time. After talked with Project Manager, Differ- Days were in the range of ± 8 days were considered as on time.

If the value of Differ- Days was higher than 8 (delay days more than 8 days) or lower than -8 (finish too early means poor planning since the test resources are occupied longer time than actually required), it will be considered as defects. The target is that try to reduce the Differ- Days which are beyond the range.

Table 3-1: A portion of the Original Test Data Collection

Test Campaign	description	Title	name	Planned Days	differ days compare with test plan	Actual executed days
AXE08A 00079	Characteristics Tests on APZ 212 55	AXE08A ST LSV5 Char55	APZ 212 55 + APG43	10	-1.0	9.0
AXE08A 00085	Robustness Tests on APZ 212 40	AXE08A ST LSV5 Rob40	APZ 212 40 + APG40C/4	4	3.0	7.0
AXE08A 00056	Short Stability Test for IPonCP on APZ 212 50	AXE08A ST LSV6 Stab50IP	APZ 212 50 + APG40	25	-0.5	24.5
AXE08A 00101	Characteristics Tests on APZ 212 33 + APG40C/2	AXE08A ST LSV6 Char33	APZ 212 3x + APG40C/2	25	0.0	25.0
AXE08A 00102	Characteristics Tests on APZ 212 40	AXE08A ST LSV6 Char40	APZ 212 40 + APG40C/4	25	0.0	25.0
AXE08A 00103	Characteristics Tests on APZ 212 50	AXE08A ST LSV6 Char50	APZ 212 50 + APG40C/2	25	0.0	25.0
AXE08A 00104	Characteristics Tests on APZ 212 55	AXE08A ST LSV6 Char55	APZ 212 55 + APG43	25	3.0	28.0
AXE08A 00105	Robustness Tests on APZ 212 40	AXE08A ST LSV6 Rob40	APZ 212 40 + APG40C/4	25	5.0	30.0

3.4.2 Current Process Performance

Figure 3-3 illustrates a detailed comparisons between Planned Days and Actual Executed Days. In 2008, there are a total of 78 finished test campaigns as part of shipment tests (There are total 80 shipment tests, 2 of them were not finished). The accumulated Differ-Days is 32.5 days, leading to an average Differ-Days of 0.416 (32.5/78) days over all the test campaigns.

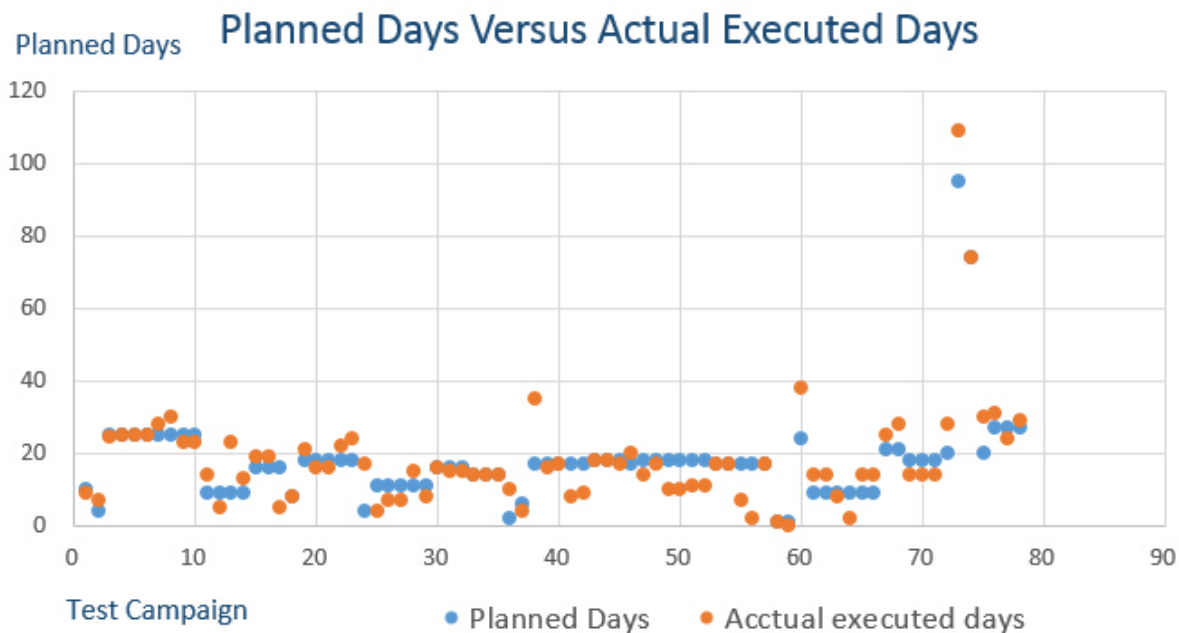


Figure 3-3: Planned Days versus Actual Executed Days

Figure 3-4 shows the Differ-Days distribution. The maximum Differ-Days is 18 which was considered an abnormal case. However, that variance in the Differ-days is quite high. The minimum Differ-Days was -15.

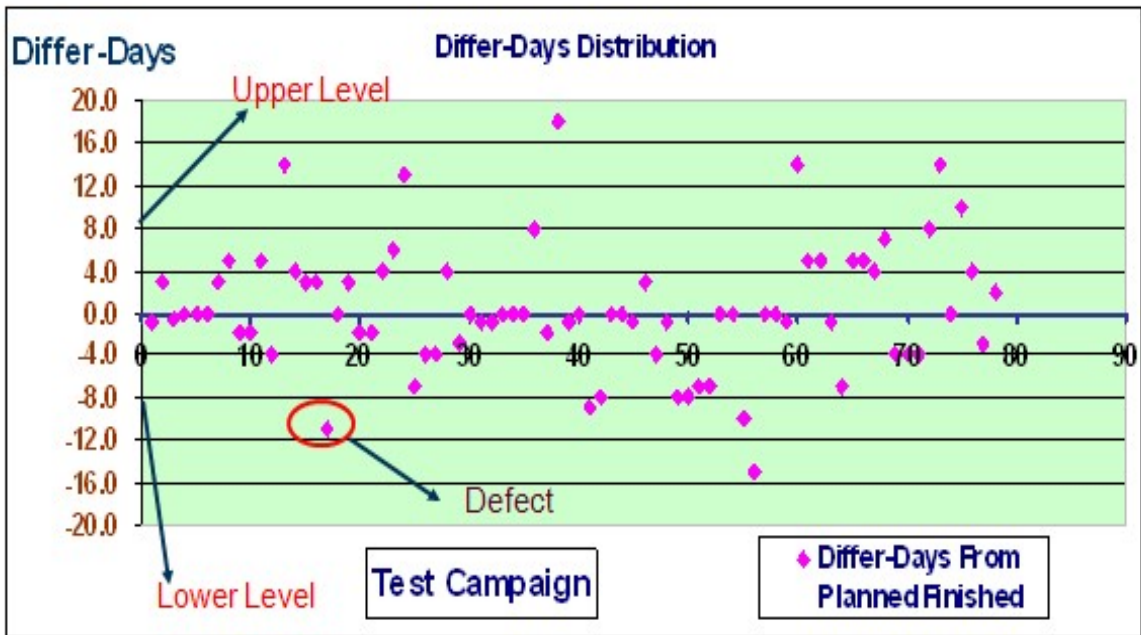


Figure 3-4: Differ-Days Distribution

We define those instance of Differ-Days smaller than 8 days (upper level) or larger than -8 days (lower level) as good performance. The others results are considered defects. In general, the test results were good. Most of the Differ-Days are in the range of ± 8 days.

Figure 3-5 illustrates the Differ-Days (“good” and “defect”) distribution. Based on the above definition of the “Defect”, there were 10 defects. The performance of test with respects to completing the shipping test on time is 87% $((78-10)/78*100\%)$.

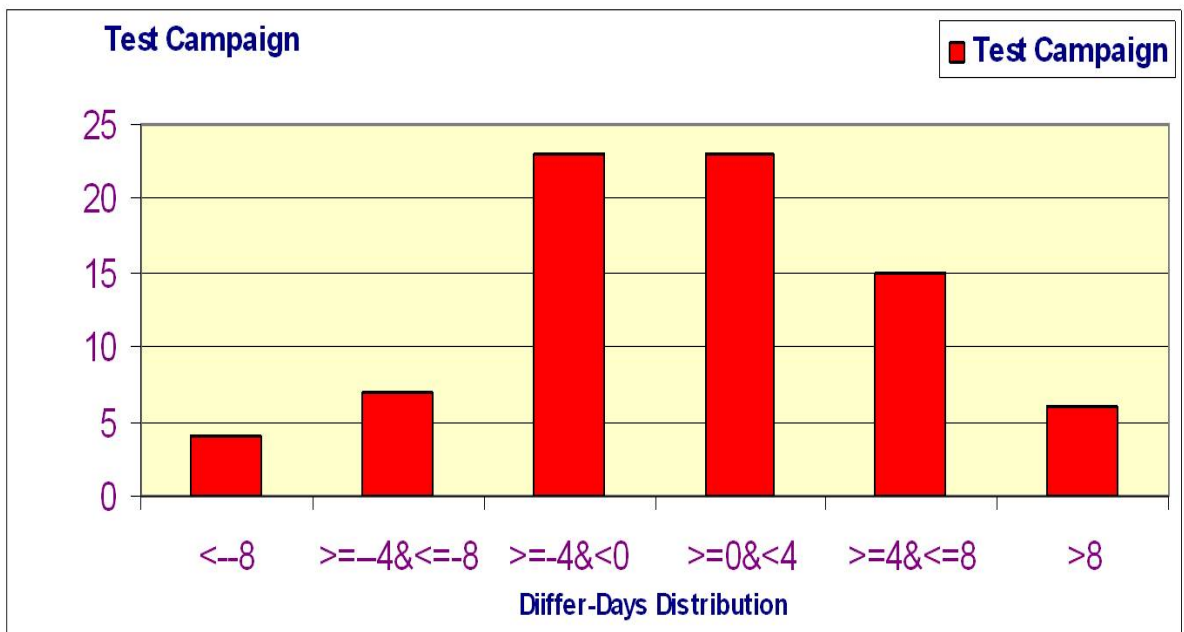
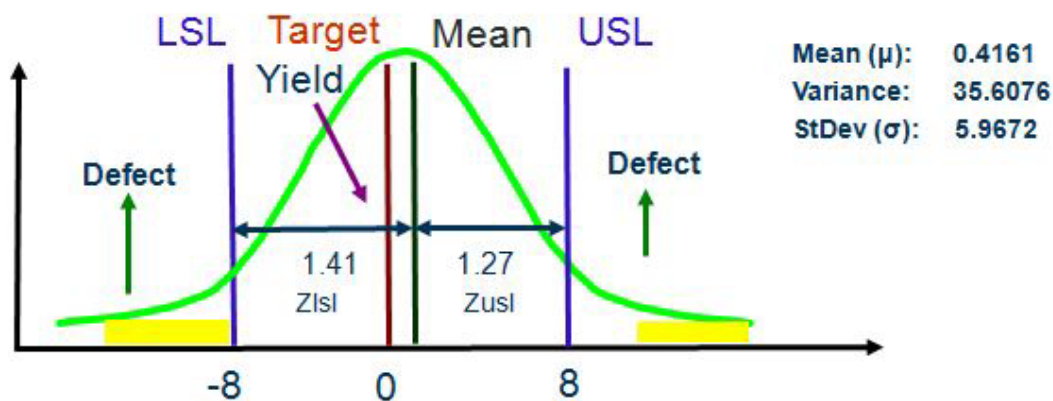


Figure 3-5: Differ-Days Distribution

3.4.3 Current Performance using Six Sigma method

Figure 3-6 illustrates the current performance in terms of the six sigma goal. As mentioned above, since the average of Differ-Days is 0.416 day, we assume 0.416 day is the mean of a Normal distribution, and then we calculated the variance to be **35.6076**. As the variance is σ^2 , σ is **5.9672**.



$$Z_{usl} = (USL - \mu) / \sigma = 1.27$$

$$Z_{lsl} = (\mu - LSL) / \sigma = 1.41$$

$$\text{Sigma level} = Z_{usl} + Z_{lsl} = 2.68$$

$$\text{Yield} = 87\%$$

Figure 3-6: Current Performance using Six Sigma method

Given these results we can calculate the Sigma level as follows:

$$Z_{usl} = (USL - \mu) / \sigma = 1.27$$

$$Z_{lsl} = (\mu - LSL) / \sigma = 1.41$$

$$\text{Sigma level} = Z_{usl} + Z_{lsl} = 2.68\sigma \text{ (sigma)}$$

The result of 2.68σ corresponds to a yield of 87%. While this result was acceptable in some cases, there is still considerable room for improvement. The next chapter describes the analysis that was done and the improvements that were suggested.

4 Analysis and Improvement

In this chapter the data analysis will be demonstrated and use Fishbone Diagram to analyze the impacts of each factors on finding the root cause. After that suggested improvement will be stated in different aspects.

4.1 Data Analysis

In order to decrease the variance of Differ-Days, the results of the shipment test campaigns need to be analyzed. We have classified the different types of Differ-Days into three categories (as shown in Table 4-1): over-estimate of actual testing time, accurate estimate of actual testing time, and under-estimate of actual testing time. In terms of these categories we see that 7.69% of the test campaigns were delayed due to some reason. 5.13% of test campaigns finished early which indicates poor planning.

Table 4-1: Test Result Analysis

Type of Differ Days	The number of Test Campaigns	Percentage	Status
Differ-Days >8	6	7.69%	Delay
Differ-Days >-8 and <8	68	87.18%	On time
Differ-Days <-8	4	5.13%	Early

4.1.1 Find Root Cause

After talking with persons with different roles (such as I&V project managers, test leaders, and testers), some of the reasons which these persons identified as the cause for the non-zero values of Differ-Days are the following:

- **Scope Collection:**

Delayed project planning increases the difficulty of resource allocation,

Delivery delays and poor quality (of the deliverables from other departments) occupied lots of time, and

Unclear documents (description or requirements) were difficult to understand.

- **Test Analysis Phase:**

There is no specific system impact analysis process in the test analysis phase and

No tester took part in the test analysis.

- Test Plan and Test Design phases:

Test plan and design phases need to be implemented well to reduce (or eliminate) re-planning and reallocation and

In order to ensure the test environment runs well proper configuration of the STP (System Test Plant) is necessary, however configuring STP is time consuming.

- Test Execution:

Trouble shooting takes a lot of time during the test execution and

Only 46% of the test cases were using automated test tools.

- Competence:

There are 16 testers in the Departments (including new employee (2) and the consultants(4) who temporary worked for some test projects, they need time to fit for the test work.)

6 of them were in the average level (Tester can perform at least one specific kind of test)

Number of top performers (only 4 experienced testers those more efficient than average) in all categories of testing personnel is limited.

4.1.2 Fishbone Diagram of root cause of Differ-Days

Figure 4-1 is a Fishbone Diagram which can be used to help find the root cause and sub cause for issues that have been identified during testing (as summarized in the previous subsection). The label "Reasons for Differ-Days" is placed at the "fish head". This represents the problem that needs to be resolved, and the labels indicating the causes of the effect, such as "Test Environment Issues" are laid out along the "bones" as classified into different sub-types along the branches (i.e., each indicating a specific sub cause). All these sub causes are marked with different color, where the color indicates the importance of the sub cause.

Fishbone Diagram of root cause of Differ-Days

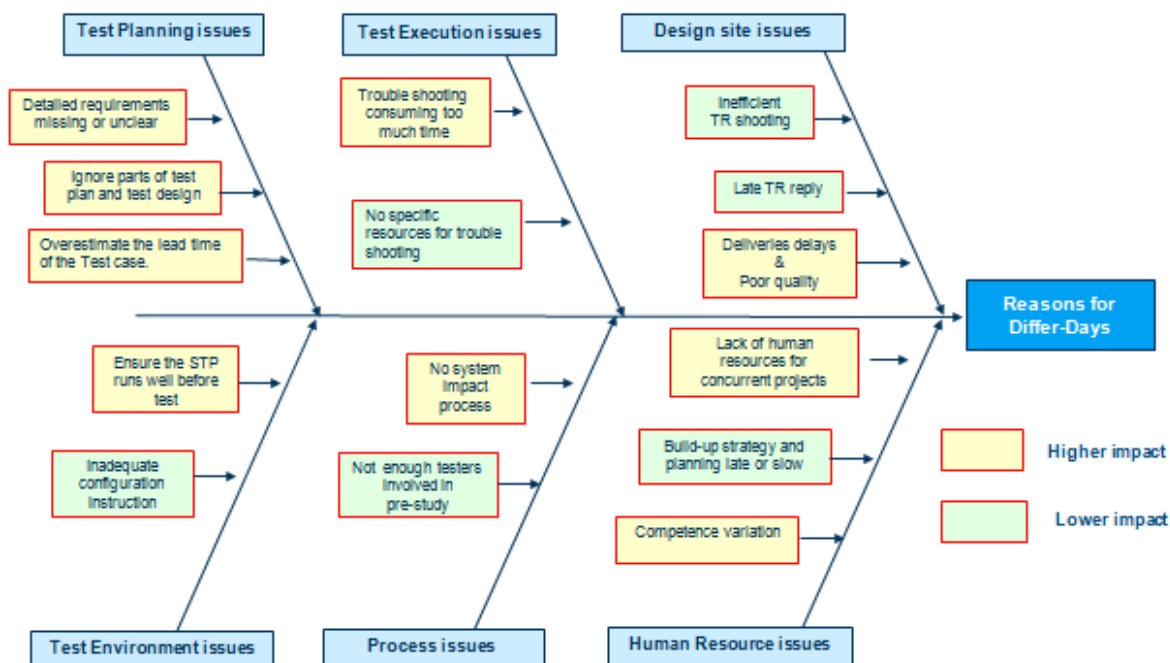


Figure 4-1: Fishbone Diagram of root cause of Difer-Days

Table 4-2 indicates the main causes with sub causes. The cells with a yellow background indicate that this sub cause had a high impact on the root cause, while the cells with a green background had a lower impact on the root cause.

Table 4-2: Six main causes with sub causes Fishbone Diagram

Test Planning issues	Test Execution issues	Design site issues
Detailed requirements missing or unclear	Trouble shooting consuming too much time	Inefficient TR shooting
Ignore parts of test plan and test design	No specific resources for trouble shooting	Late TR reply
Overestimate the lead time of the Test case.		Deliveries delays & Poor quality
Test Environment issues	Process issues	Human Resource issues
Ensure the STP runs well before Test	No system impact process	Lack of human resources for concurrent projects
Inadequate configuration instruction	Not enough testers involved in pre-study	Build-up strategy and planning late or slow
		Competence variation

4.2 Suggested Improvements

Different factors have been found that influences the target of the measurement: Differ-Days. This subsection describes the suggested improvements needed to solve the issues identified during the data analysis.

4.2.1 Improvements in the Scope Collection Phase

The previous sections mentioned that the late delivery and poor quality of the scope collection process consumed too much time. The following improvements are suggested to address this sub cause:

- **I&V Project Managers need to have close cooperation** with the delivery department. When delivery will be delayed more than 3 days the functionality should be moved to next LSV (and hence tested in the next test period).
- **At least one tester should be involved** in the early stage to verify the delivery quality. The testers should share their time schedule and current workload to help the I&V Project Manager and test leader to decide which and how many of requirements can be verified and try to evaluate the lead time for the test cases accurately.
- **A list of some common “Questions & Answers” can be added** at the end of the scope document to help the tester to avoid some misunderstandings. This list can be updated by both parties.
- If the quality of the system being tested cannot achieve the required standard, then the requirements could be rejected or the functionality moved to the next LSV.
- **I&V Project Manager should publish the test schedule every week** so that testers can coordinate their time schedules, check the test plant’s status, and report their current workload to their line managers in advance. Using this feedback the tester leader can start to prepare the resource allocations.

4.2.2 Improvements in the Test Analysis Phase

Prior to the start of this thesis project there was no tester involved during the test analysis and there is no test impact analysis during the analysis phase. This is especially a problem when a Change Request (CR) is received. The solution is also involve at least one tester during the pre-study phase in order to improve prediction of problems and to try to discover potential issues in order to avoid wasting the resources.

The following improvement is suggested to address this sub cause:

- **Add one more process System Impact Analysis before Test Analysis phase**
The purpose for adding this process is reducing the risk of the delivery and checking the impact for the project, such as the influence of the time schedule, test plant preparation, resources cost etc.

Figure 4-2 shows the improved shipment test process.

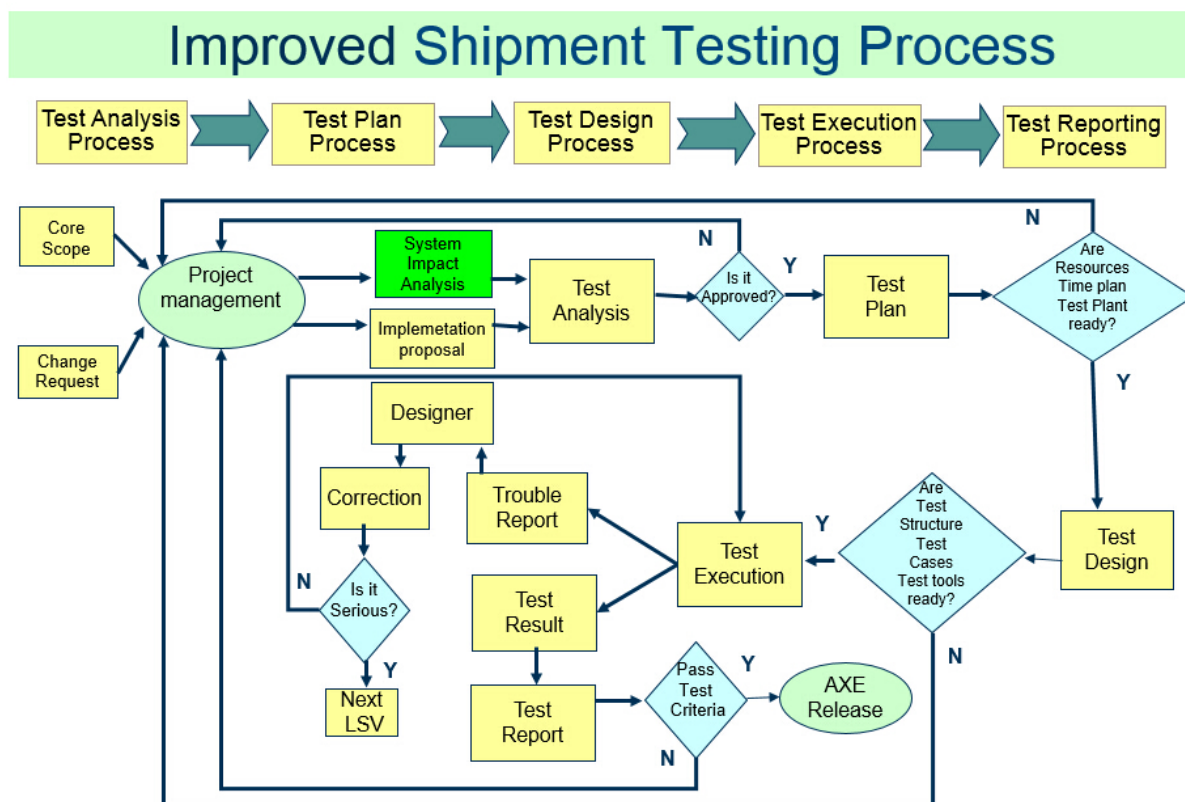


Figure 4-2: Improved Shipment Test Process

4.2.3 Improvements in the Test Plan and Test Design phases

The test plan is always changing during the test activities for different reasons, such as a tester being overloaded; there are a limited number of test plants; and even if one can get a test plant, to configure the test plant requires the tester to spend a couple of hours to configure the test plant. In each of these cases the test plan needs to be re-done.

The following improvement is suggested to address this sub cause:

Testers should be involved during the whole set of activities, their feedback is very important as they can check the test plan and coordinate with other the testers who share the same test plant. They can also share their configuration experiences with regard to the STP. Also the testers can immediately give feedback about potential difficulties and issues, thus the test leader and I&V project manager can consider this feedback in advance, thus they can potentially avoid the need for re-planning.

If a tester finds some of the requirements unclear or some detailed requirements missing, they can also report this to the test leader or I&V project manager, thus the decision making team can support the testers by clarifying the requirement as soon as possible, again avoid the need for a re-design.

4.2.4 Improvements in the Test Execution phases

One of the most important sources of delay in the test execution phases is that trouble shooting consumes too much time. When testers find errors, they need to analyze and identify the cause of these errors. The reasons for failures can be of several different types:

- The test cases themselves may have some failures,
- Test plant problem, with either hardware or software,
- Test process scripts may have some bugs,
- For automatic test cases, the test tools can cause some issues, and
- For manual test cases*, human being can also make mistakes.

There is no standard process to guide the testers (especially new testers) about how to identify the cause of errors nor how to resolve these issues when they occur. The current main channels for finding a solution are:

1. The testers check the technical reference document and solve the problem by themselves,
2. New testers ask for help from more experienced testers, and
3. The testers have daily or weekly reviews, where they discuss the problems and solutions that they have found.

The following improvements are suggested to address this sub cause:

- **Set up a single Test Knowledge Base.** This database records failures and their solutions. The database can have different categories, such as the test plant, test tools, and so on. Testers can upload their trouble shooting experience into the database and they can also find how to resolve previously identified issues by checking the relevant category or searching for specific “key words”. Sharing experience can help testers reduce the time they need to spend “looking for” a solution. This database is also one of the most efficient ways to virtually increase their test experience.
- Set the Goal for automated test cases to at least 65%

I & V project manager and test leader can request that the designers develop more test tools. Automated test tools can bring plenty of benefits for the testers, including:

- By automating the test execute tests can be executed precisely, reliably, and repeatable, thus human errors can be avoided,
- The test tools can be reused and reprogramed for use in a similar test environment,
- Automated tools are faster than human executed test cases, thus saving time and human resources, and
- Automated testing can reduce the cost for regression testing.

A lot of resources will be saved when a higher percentage of automated tools are utilized.

4.2.5 Improvements in Competence

In reality, it is difficult to evaluate the competence of the testers who have different knowledge background and different amounts of working experience. In shipment test section, two new employees who graduated without any test experience and 4 consultants joined the team and need time to be familiar with the test process and environment. Additionally, the number of test experts is limited. How to improve their competence is one main target for the Project Managers. If experienced testers can share their knowledge and experience in a proper way, then the aggregate team competence will be enhanced.

* At the time of this study only 40% of the tests were automated.

The following improvement is suggested to address this sub cause:

Experience sharing activity is one of the most efficient ways for testers to improve their effective skill level and experience.

Typically there are 15-16 testers in one section. If these testers select the 3 most experienced testers as the test expert in their section, then each of these test experts prepares one 30 minute training presentation every week for the other testers. The topic of this presentation can be a single test case, some experience in a test scenario, or one knowledge point. In this case, each tester will get 0.5 hours * 3 expert tester presentations * 4 weeks per month * 10 months per year* or 60 hours of training by test experts per year.

While the total number of training hours spent on training for 15 testers will be $60 \times 15 = 900$ hours; the result of this training can improve the testers' competence, thus potentially reducing the total cost of testing (i.e., the aggregate 900 hours spent in training can save more than this number of hours of testers time).

* Note that we have used 10 months per year rather than 12 months per year to correct for the vacations and holidays that the testers will typically have.

5 Control of the improved process

Prior to this phase most of the suggested improvement points had been implemented in the test activities. The sections of this chapter describes the control activities carried out and the result of this improved control.

5.1 Delayed delivery of the test requirements

I&V project managers made an agreement with the delivery departments: The I & V test team would receive a notification of a coming delivery one week earlier than before. I&V project managers kept track of the delivery status and informed the test leaders. Based upon this status the test leader could prepare resources allocations in advance. Even though there were still some urgent requirements that were received without advanced notification and this scenario cannot be avoided, the I&V project managers could negotiate with test leaders to find a compromise solution that suited both parties. The process was executed for 3 months, during which time most of the deliveries were on time, the resulting resource allocation was more reasonable and acceptable to all concerned.

5.2 Improve the quality of the delivery

To avoid misunderstanding and unclear delivery requirements, a “Questions & Answers” list was added at the end of the delivery requirements. This list proved to be very useful as the testers could understand the requirements more quickly than ever before. Additionally, rather than guessing they were able to confirm with the requirements with the designers. This list could be updated as necessary.

5.3 Involve a tester in the whole set of test activities

Involving a tester in the whole set of test activities, especially starting with the pre-study phase and scope collection, test analysis, and test plan brought lots of benefits, including the following:

- In the scope collection phase, since the testers know the status of test plant and can evaluate the difficulty of the test requirements, they could help the tester leader reject requirements which were too complicated, less important requirements, or non-testable. Also they could concisely summarize the requirements at an early state, thus helping the delivery team output a clear set of requirements.
- Testers thought about their testing activities and always had an outlook which the designers did not have; hence they were able to make the designers aware of some defects even *before* testing.
- In the test analysis, test plan, and test design phases, testers could evaluate the requirements and do a risk analysis. The requirements that are essential to the business could be marked as “higher priority” and requirements that might make test execution difficult to finish on time could be marked as “high risk”.
- Due to being involved in the test plan and test design phases, the testers understood earlier all the test requirements, hence they were better able to allocate the test plants and plan the best test schedule. They could also better designate cases to maximize the utilization of automated tools.
- As the testers took part in the early stage, they could help avoid the need for re-planning and re-design; hence the number of the CRs decreased. The I&V project manager and test leader also experienced less pressure on their test plan and test design.

5.4 Add System Impact Analysis before Test Analysis phase

The suggested impact analysis processes were implemented in the overall process before test analysis. The impact reports were generated by the test leader and testers. In these reports, some key points could be highlighted, such as:

- Impact on the test scope,
- Test resource needs,
- system test platform (STP) impact,
- Impact on the test plan and test cases,
- Time schedule impact, and
- Risk analysis.

With this impact analysis process, project management could get more information before the start of test analysis, decreasing need for re-planning and re-design; while increasing the quality of the test plan.

5.5 Set up a “Knowledge Base”

In order to reduce the time for troubleshooting, an internal trouble shooting forum was created. The forum invites experienced testers to share their troubleshooting experience case by case. A lot of cases are general and can be found in many test scenarios. The result is that new testers can easily find similar test cases by searching for specific key words. Experience sharing helped the new testers learn faster than they would learning simply based upon their own direct experiences.

The feedback from the testers was very positive about this knowledge base.

5.6 Experience Sharing Activities

As Section 4.2.5 mentioned, the shipment test team implemented the suggested experience sharing activities internally. Unfortunately, since the experts were always overloaded, a presentation could not be held every week. Even though the total number of presentations was not as many as desired, young testers found that they could learn a lot from the presentation of these earlier test cases.

The test team found another way to share their experience by assigning each of the new testers a more experienced “tutor” to help them solve specific cases. Also the departments picked one person to give additional general training, including history, product, workflow, policies of the company, and introduction to the department to all of the new testers.

5.7 Result

The above control method was implemented in the 2009 AXE shipment test. From January to March 2009, there are 15 test campaigns were executed. Figure 5-1 shows the Differ-Days Distribution for this period of 2009. During this period only one defect (defined according to the criteria in Section 3.4.2) was found. Moreover, the rate of finishing testing on time is $14/15 = 93.33\%$.

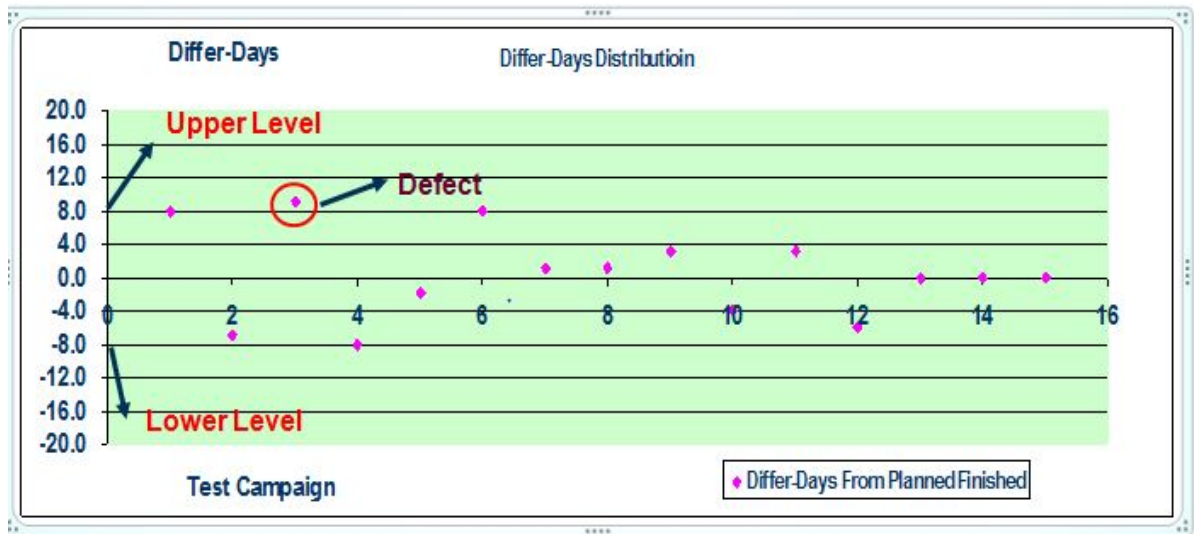


Figure 5-1: Differ Days Distribution 2009

Figure 5-2 shows Improved Performance of the shipment test. As mentioned above, since the average of Differ-Days is 0.4 day, we assume that 0.4 day is the mean of this Normal distribution in our use of the Six Sigma methodology, then the variance (σ^2) is calculated to be is **28.2571**. Therefore σ (sigma) is **5.3157**.

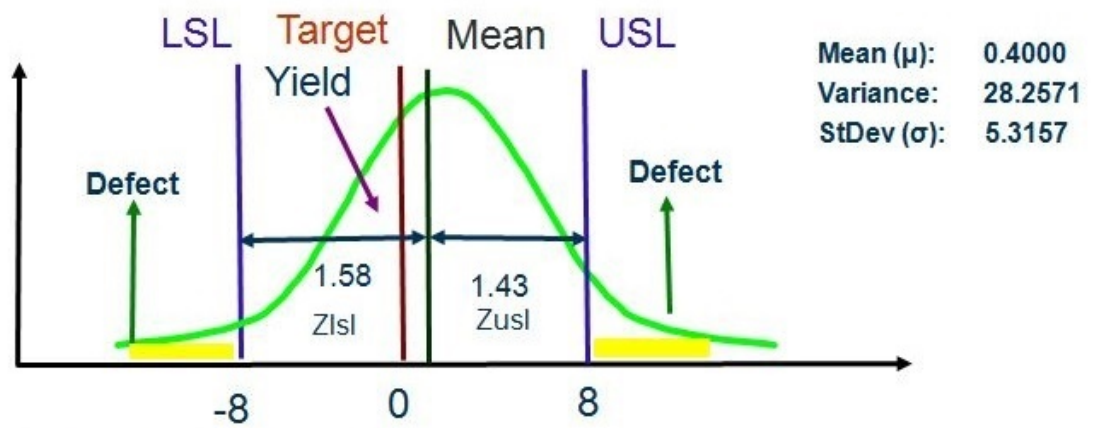
Given these results we can calculate the Sigma level as follows:

$$Z_{USL} = (USL - \mu) / \sigma = 1.43$$

$$Z_{LSL} = (\mu - LSL) / \sigma = 1.58$$

$$\text{Sigma level} = Z_{USL} + Z_{LSL} = 3.01 \sigma \text{ (sigma)}$$

The result of 3.01 σ corresponding to a yield of 93.33%. The project goal is fulfilled and this result is a clear improvement over the earlier 2.68 σ (sigma) (corresponding to a yield of 87%) there is still room for improvement before the process reaches six sigma. However, for the purposes of this master's thesis project, the project's goal was considered to be achieved.



$$Z_{usl} = (USL - \mu) / \sigma = 1.43$$

$$Z_{lsl} = (\mu - LSL) / \sigma = 1.58$$

$$\text{Sigma level} = Z_{usl} + Z_{lsl} = 3.01$$

$$\text{Yield} = 93.33\%$$

Figure 5-2: Improved Performances

6 Conclusions and Future work

In this chapter the conclusion of applying six sigma in shipment test will be given. Continuing to improve the sigma level by reducing the range of Differ-Days will be part of the Future work and some reflections on the project also be described.

6.1 Conclusions

First we can conclude that the applying six sigma in shipment test had a positive effect and improved the test performance (in terms of finishing testing on time) and increased delivery quality.

After investigating the current process and performance in the shipment, a new business model was defined in order to reduce the Differ-Days leading to an improvement to 93.33% of on time delivery. Based upon the analysis of the data from measurements of the process in 2008, the root cause (and sub causes) was found. This leads to a number of proposals for improvements. A number of effective improvement proposals were identified and then implemented. Additional processes were added, and a knowledge based setup and training program was executed. These proposals were evaluated based on their subsequent control during test activities in the first quarter of 2009. An analysis of these improvements showed that the project's goal was fulfilled.

The PDU AXE I&V section continued to apply the six sigma methodology following this thesis project and today (2015) the sigma level of the shipment test process is 3σ . Details of these further improvements are outside the scope of this thesis.

6.2 Future work

In this project, we consider the **Differ- Days** in the range of ± 8 days as **on time**. And current performance is acceptable. However, the performance of shipment test still has the space to improve if the Differ-Days in the range of ± 4 days was considered as **on time**. If that so, some current good performance test campaigns will be considered as defects (the Differ-Days between 4 and 8 or between -4 and -8) and the new sigma level will be lower than 3 sigma. In order to reach 3 sigma requires better planning (both for the human resources and Test environment), clearer requirements and design documentations, faster response on the TR reports,

If the sigma level can still reach to 3 sigma or even a little bit lower, in the real test performance perspective, it would be a remarkable improvement because more test campaigns will be finished with smaller Differ-Days and Test Performance will be more efficient. Additionally from a statistical perspective (Normal Distribution plot), the good products are more concentrated in the middle, thus the shipment test process is more controllable than ever before.

In order to improve the efficiency of shipment and reduce the cost of testing, reducing the numbers of CRs can be defined as a project target by using six sigma methodology in future work. CRs can occur before or during the test activities and the process of handling the CRs can be optimized.

6.3 Reflections

This project studied how to improve test quality in shipment testing by using six sigma methodology. The author researched the whole process of the shipment test and had several private interviews with test experts, test leaders, line manager, and new employees to summarize the key issues and their difficulties during the test activities. This enabled the project goals to be defined as: try to reduce the Differ-Days in the shipment test, measure the current performance, and do data analysis. Some improvement proposals came out and were implemented in the test process. Subsequently the managers could better control the process and defects were reduced, hence there was a positive economic effect for the company.

Implemented six sigma methodologies could bring multiple important values to the test performance. Using six sigma revealed that adding one more process (**System Impact Analysis before Test Analysis phase**) could reduce the risk of the delivery being delayed and that checking the impact of adding processes on the project is necessary. The project managers gained more understanding about the influence of the time schedule, test plant preparation, resource costs, and adjusted their plans to minimize the total cost. Moreover, six sigma methodology also gave some suggestions as to how to reduce the lead time and reduce costs during the different phases of test activities (Test Design, Test Execution, etc.). Setting up a Knowledge Base and Experience Sharing activities was shown to improve the competence of the employees *without* add any cost. The six sigma method can be learned and could be implemented in other process, such as reducing the number of CRs (as mentioned in the section above on future work), reducing the lead time of troubleshooting, or in other departments' daily activities to improve quality.

Cost reductions, improvements in efficiency, reduction in lead time, and higher quality of the product being delivered ultimately benefit consumers and shareholders. Improvements in the processes benefit both managers and employees. Reducing the number of days spent in shipment test reduces the power consumed by testing (both the equipment under test and the test equipment). Reducing the number of defective subsystems reduces the amount of electronic scrap that needs to be recycled. Hence the improvements in the control of production using the six sigma methodology have positive economic, social, and sustainability results.

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* The title and publisher of [2] have been elided as they are confidential.

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