Applying Six Sigma in Software Companies for Process Improvement

Adnan Rafiq Khan
Long Zhang
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Contact Information:
Author(s):
Adnan Rafiq Khan
Address: Folkparksvagen 1905, 37240 Ronneby, Sweden.
E-mail: adnanrafiqkhan@gmail.com

Long Zhang
Address: Villa Flora 951, 37236 Ronneby, Sweden.
E-mail: zhll0154@gmail.com

University advisor(s):
Conny Johansson
(Head of Department, Department of Systems and Software Engineering)
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ABSTRACT

Modern society has a higher demand for quality than it had before. There is a Plethora of quality improvement techniques available which makes it harder for companies to decide which one to apply. They need support in this decision and in knowing how to apply the chosen techniques, if they want to improve their business and stay competitive.

Six Sigma approach is a very successful manufacturing quality improvement tool. In the last two decades, it has helped many companies to success. Recently, the Six Sigma approach was introduced in the software development industry. Some software companies have been trying to adapt Six Sigma for their business and development processes. But there are misconceptions about the applicability of Six Sigma in software’s. Furthermore there is no generic software quality improvement solution based on Six Sigma. So there is a demand to debunk the misconceptions related to the applicability of Six Sigma. And to develop a generic software company quality improvement solution based on Six Sigma approach. In this thesis we take a first step towards such a solution.

The thesis starts from Six Sigma concept identification and manufacturing investigation. After conducting interviews, a case study and several case studies reviews, we detail our method. We expect thesis result to be useful for software companies when applying Six Sigma in their company for process improvement.

Keywords: Software Quality, Quality Improvement Tool, Six Sigma and Process Improvement
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1. INTRODUCTION

This chapter mainly discusses why authors have chosen Six Sigma for their master thesis and what will be done in this field. The description is divided into four parts – Motivation, Aims and Objectives, Research Questions, and Research Methodology. And also, the outline of the entire paper is presented by the end of this chapter.

1.1 Motivation

In recent years, the companies and organizations around the world are showing great interests in quality. Six Sigma approach is a structured quantitative method which is invented by Motorola in 1986 for improving the product quality [1]. Its aim is to enhance organization’s performance by using statistical analytic techniques [2]. After two decades of successful implementation in manufacturing, Six Sigma is approved as an effective methodology for improving quality.

Nowadays, some researchers believe that Six Sigma can bring large benefits for software companies [3, 4]. Furthermore, software companies have already started to implement Six Sigma approach, like Ericsson, Tata Consultancy Service, etc [5-7]. However, there are still some problems and misconceptions existed about the applicability of Six Sigma in software companies.

Our work can help to debunk the misconceptions about the applicability of Six Sigma in software companies. And provide steps for software companies to implement Six Sigma. The scope of this paper is demonstrated in Figure 1.1 which shows the relationship between Quality and Six Sigma.

![Figure 1.1 Relationships between Six Sigma and Quality.](image)

1.2 Aims and Objectives
The main aim of this paper is to provide steps for software companies who want to implement Six Sigma for process improvement. To achieve that, following objectives shall be reached:

- Identify the differences of Six Sigma in manufacturing and software companies.
- Discuss the acceptance of Six Sigma in software companies.
- Compare the academic research results with the reality of software companies.
- Identify the state-of-art of Six Sigma in software.
- Screen out the suitable Six Sigma tools and techniques for software companies.
- Discuss the future work for Six Sigma in software companies.

1.3 Research Questions

To reach the goal of the thesis, the following research questions shall be answered.

- What are the definitions of Six Sigma?
- What is the condition of Six Sigma in manufacturing? Are there any hurdles when we implement it to software companies?
- Why software companies choose Six Sigma?
- What kind of tools and techniques are used in Six Sigma? Which of them are suitable for process improvement in software companies?
- What is the state-of-art for the implementation of Six Sigma in software?
- What are the steps to implement Six Sigma in software companies for process improvement?
- What is the further work for Six Sigma in software?

1.4 Research Methodology

A mixed methodology will be used which include both qualitative and quantitative research. And this mixed methodology has been used for authors’ research. Both qualitative and quantitative research methodologies were used [5].

In the qualitative research methodology part, a detailed and comprehensive literature study have been carried out. The literature study consists of articles, books, web materials, discussion forms and others. The literature study is used to find out the characteristics of Six Sigma, the tools and techniques used in Six Sigma, and to analyze the suitability of these tools and techniques for process improvement in software companies. A list of tools and techniques have been provided, which are helpful for Six Sigma implementation. With the help of the literature study, the condition of Six Sigma in manufacturing has been identified. After completely understanding the usage of Six Sigma in manufacturing, the research moved to follow research questions – applicability of Six Sigma in software and why software companies choose Six Sigma for process improvement. In order to answer these research questions, different views which provided by software specialists have been discussed. Then authors analyzed the difference between manufacturing process and software process. Once the differences are clear, we can easily find out the applicability of Six Sigma for software.

In the quantitative research methodology part, two interviews have been conducted, one case study, and three case studies are reviewed. The first interviewee was one employee in a world-class manufacturing company. The company has over 5 years experience in implementing Six Sigma. And the interviewee currently is a Green Belt who have participated more than three Six Sigma projects. And the interview was conducted through phone. Before interview, authors have made enough preparations which include company
background investigation, question list preparation, and some interview skill learning. To have a best communication, a quite environment and one backup phone have been prepared. Regarding question list, it was generated after Six Sigma approach studying and company background learning (question list is presented in Appendix C). The motivation behind the interview was firstly to understand how Six Sigma is implemented in a manufacturing company. Secondly how Six Sigma improves a particular manufacturing process. And the employee has additional provided documents regarding to a real Six Sigma case study. The case study shows how a particular manufacturing process is improved using Six Sigma. The second interview was in a company, where they have implemented Six Sigma for Software’s. The motivation behind the interview was firstly to understand how Six Sigma is implemented in Software Company. Secondly how it improves particular software processes. The interviewee was one employee in the company. He was working as a quality head. He had trainings in Six Sigma Green Belt and Black Belt. We have conducted the interview with the help of a questionnaire shown in Appendix D.

To have a farther research on Six Sigma approach, three case studies have been found from previous researchers’ work [6-8]. The motivation behind the case studies review is to find out the state-of-art for Six Sigma’s implementation. The companies which provided those cases came from three different fields – software, human resource and consultancy. That is good for our research. By comparing their differences and similarities, author have gain very interesting and useful findings. Those findings were integrated with Six Sigma implementation model, and presented as the research final results for software companies and researchers.

To validate the threats in authors’ research, a validation was conducted at last. Learning from [9], the validation was made up by four parts – internal validity, construct validity, conclusion validity and external validity. With help of mixed research methodology and reasonable validation, authors’ research is believed to fulfill both correctness and authenticity’s requirements.

1.5 Outline

Chapter 2 briefly introduced the background of quality and software quality, and described Six Sigma approach in detail. Chapter 3 described the tools and techniques that can be used in Six Sigma activities. Chapter 4 analyzed the implementation of Six Sigma in manufacturing, and presented experiences from manufacturing companies. Chapter 5 firstly identified the differences between manufacturing and software process, and then discussed the acceptance and motivation for applying Six Sigma in software companies. Chapter 6 presented two interviews, a case study, and three case studies are reviewed. The case studies reviews are related to the application of Six Sigma in different fields. Chapter 7 provided a method for helping software companies to apply Six Sigma approach in their development process. Chapter 8 is on the discussion on the results, and about validity threats. The last chapter 9 presents research conclusion, research questions revisited, contributions, and talked about some further works for Six Sigma.
2 INTRODUCTION TO QUALITY AND SIX SIGMA

In recent decades, the companies and organizations around the world are showing great interests in quality. Especially in 1970s and 1980s, the success of Japanese industry stimulates the whole world to focus on quality issues [10]. The experience from them proved that the requirements and expectations of customers are the key factors which decide the quality.

2.1.1 Definition

The word “quality” comes from the Latin “qualitas”, and Cicero (a roman orator and politician, 106-43 B.C.) is believed to be the first person who used the word [10]. Until the a few decades before, the concept of quality has been significantly extended as we know it today. There were many popular definitions for quality concept. Table 2.1 [10-14] lists some of them.

<table>
<thead>
<tr>
<th>Year</th>
<th>Definer</th>
<th>Definition of quality concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>1931</td>
<td>Walter Shewhart</td>
<td>“...there are two common aspects of quality. One of these has to do with the consideration of the quality of a thing as an objective reality independent of the existence of man. The other has to do with what we think, feel or sense as a result of the objective reality. In other words, there is a subjective side of quality”.</td>
</tr>
<tr>
<td>1951</td>
<td>Joseph Juran</td>
<td>“Fitness for use”.</td>
</tr>
<tr>
<td>1979</td>
<td>Philip Crosby</td>
<td>“Conformance to requirements”.</td>
</tr>
<tr>
<td>1979</td>
<td>Genichi Taguchi</td>
<td>“The losses a product imparts to the society from the time the product is shipped”.</td>
</tr>
<tr>
<td>1985</td>
<td>Edwards Deming</td>
<td>“Quality should be aimed at the needs of the customer, present and future”.</td>
</tr>
<tr>
<td>1990</td>
<td>Myron Tribus</td>
<td>“Quality is what makes it possible for a customer to have a love affair with your product or service.”</td>
</tr>
<tr>
<td>2000</td>
<td>ISO 9000: 2000</td>
<td>“The degree to which a set of inherent characteristics fulfills the requirements, i.e. needs or expectations that are stated, generally implied or obligatory”.</td>
</tr>
<tr>
<td>2004</td>
<td>Bengt Klefsjö and Bo Bergman</td>
<td>“The quality of a product is its ability to satisfy, and preferably exceed, the needs and expectations of the customers”.</td>
</tr>
</tbody>
</table>

From the definitions above, we can find some interesting common points. Firstly, almost all factors are conducted around customers. In another word, it can be said as customers decide the quality (e.g. Juran in 1951, Deming in 1985, and Tribus in 1990). Secondly, according to customer, two things are commonly considered as which shall be fulfilled – customer requirements and customer expectations. The requirements are what customers request and demand. These are the basics of the quality. The expectations are what the customers expect and look forward to. Sometimes, the customers do not know what they really need. So that demands developers to have a good understanding about the customer’s minds.
Although the definitions in Table 2.1 are similar, they also have distinctions which make them different. For example, “fitness to use” (Joseph Juran, 1951) is defined from end user’s view. In contrast, Philip Crosby (1979) defined the quality as “Conformance to requirements” from producer’s view. The reason is their backgrounds are different.

A further identification of these differences is conducted by Gavin in 1984. Five approaches to the quality concept are claimed which include transcendent-based, product-based, user-based, manufacturing-based, and value-based, see Figure 2.1 [15]. From transcendent-based view, the quality can be identified by experience. Mostly is very successful. But from this point of view, the quality is not defined very clearly. This problem can be solved by product-based approach. The quality can be exactly defined and measured. However, the cost for quality cannot be judged by customer. User-based approach’s opinion is that the quality is decided by customer. Customer’s satisfaction is the only scale which reflects product quality. Manufacturing-based perspective relates to accomplish the requirement specification. Reducing defects is the main task of quality improvement. According to value-based approach, the quality relates to cost and price. Generally price is decided by cost. A high quality product means that the customers are willing to pay for it. In Gavin’s view, an organization cannot have just one approach for the quality concept, but that different parts of organization need different approaches [15-17].

![Figure 2.1 Five approaches of quality concept from Gavin (1984).](image)

In quality issues, customer plays one of most important roles. A high quality product shall fulfill customers’ requirements, and satisfy their expectations. Due to Gavin’s theory [15], there are several approaches for quality concept. An organization cannot have just one approach, but it uses different approaches in different parts.

### 2.1.2 Why Quality Improvement

“Quality is free. It is not a gift, but it is free. What costs money are in-quality things - all the actions that involve not doing jobs right the first time.” — Philip Crosby [12]

Many companies pay a lot in correction, i.e. 80% of the cost in a Software Engineering (SE) project is commonly related to after-delivery corrections. And we also found [18]:

- Unsatisfied customers tell in average 10 persons about their bad experiences. 12% tells up to 20 other persons.
- Satisfied customers tell in average 5 persons about their positive experiences.
- It costs 5 times as much to gain new customers than keeping existing ones.
- Up to 90% of the unsatisfied customers will not make business with you again, and they will not tell you.
- 95% of the unsatisfied customers will remain loyal if their complaints are handled fast and well.
All above motivate us to improve quality. Improved quality can affect the success in many different ways [10]:

- More satisfied and loyal customers
- Lower employee turnover and sick leave rates
- A stronger market position
- Shorter lead times
- Opportunities for capital release
- Reduced costs due to waste and rework
- Higher productivity

Figure 2.2 [13] demonstrates the importance of quality which expressed by Deming in 1986. In this figure, Deming connects improved quality with company prosperity.

As we seen, improving quality does not mean losing money in business. Proper improvement will bring organizations much more benefits.

2.1.3 Software Quality

Modern society is highly dependent on software products, i.e. bank system, telephone network, supermarket system, etc. As said by [19], “the general public usually blamed ‘the computer’, making no distinction between hardware and software”. However, millions facts of software failures alert us to focus on software quality in everyday lives. Today, software customers are demanding higher quality and are willing to pay a higher price for it [20]. Improving quality has become the common goal of each software development phase [21].

Similar with general quality concept mentioned in Section 2.1, high quality software shall have following factors [22]:

- Developing in the right way.
- Matching the requirement specification.
- Good performance meeting customer’s expectations.
- Fitness for use.

Combining with Gavin’s five approach of quality concept [15], Kitchenham and Pfleeger describe software quality in another way [19]:

- *Transcendental view* – Software quality is thought as an ideal, but may never implement completely.
User view – High quality software shall meet the user’s needs, and have a good reliability, performance and usability.

Manufacturing view – This view focuses on product quality during production and after delivery to avoid rework. Adopted by ISO 9001[23] and the Capability Maturity Model [24], the manufacturing approach advocates conformance to process rather than to specification. Hence, to enhance product quality, improving your process is very much essential [25].

Product view – Be different with above views, product view assesses quality by measuring internal product properties. Software metrics tools are frequently used.

Value-based view – High quality product always means a high cost. Different product purchasers always have the different value view. So that this approach puts much more efforts on considering the trade-offs between cost and quality.

Different views can be held by different groups involved in software development, i.e. customers or marketing groups have a user view, researchers have a product view, and the production department has a manufacturing view. It is not enough that only one view is identified explicitly. All views influence each other. Measuring each view clearly is one of assurances for high quality [19].

2.1.4 Software Process Improvement

Based on five approach of quality concept, process improvement aims to have a better control in software development. Managers or organizations generally divide the whole project into smaller phases, such as requirement analysis, planning, coding, testing, releasing, etc. These phases are known as the Software Project Life Cycle (SPLC) [26]. Within each project phase, we use iterative processes to achieve phase’s deliverables. Figure 2.3 shows a typical iterative of project processes. Project processes are distributed into five groups – initiating process group, planning process group, executing process group, monitoring and controlling process group, and closing process group.

![Figure 2.3 A typical project processes cycle [26].](image)

Quality in a software product can be improved by process improvement, because there is a correlation between processes and outcomes. As defined by IEEE [27], process is “a sequence of steps performed for a given purpose.” It provides project members a regular method of using the same way to do the same work. Process improvement focuses on defining and continually improving process. Defects found in previous efforts are fixed in the next efforts [28]. There are many models and techniques for process improvement, such as CMMI, ISO9000 series, SPICE, Six Sigma, etc.

2.2 Six Sigma

2.2.1 History
In 1980s, Bob Galvin the CEO of Motorola was trying to improve the manufacturing process. The Senior Sales Vice President Art Sundry at Motorola found that their quality is extremely bad. They both decided to improve the quality. Quality Engineer Bill Smith at Motorola in 1986 invented Six Sigma. It was applied to all business processes. In 1988 Motorola Won the Malcolm Baldrige Quality Award, as a result other organizations were also interested to learn Six Sigma. Motorola leaders started teaching Six Sigma to other organizations. Initially Six Sigma was invented to improve the product quality by reducing the defects, but later Motorola reinvented it. The new Six Sigma is beyond defects, it focuses on strategy execution. It became a management system to run the business. It was invented for an improvement in manufacturing industry but now it is applied in almost every industry i.e. Financial Services, Health care and Hospitality. Originally Six Sigma was introduced in United States but now it is in applied in many countries around the world [29, 30].

### 2.2.2 Definition

Six Sigma is a structured quantitative method which is originally invented for reducing defects in manufacturing by Motorola in 1986 [1]. Its aim is using statistical analytic techniques to enhancing organization’s performances, and to improving quality [2]. Since Six Sigma has evolved over the last two decades, its definition is extended to three levels [31]:

- Metric
- Methodology
- Management System

Six Sigma approach satisfies all the three levels at the same time. Those levels are discussed in the following sections.

### 2.2.3 As a Metric

“Sigma” is the Latin symbol “σ”. Here we use it to symbolize how much deviation exists in a set of data, and that is what we called standard normal distribution, or the bell curve. The normal distribution, also called the Gaussian distribution, is used for continuous probability distributions, see curves in Figure 2.4 [32]. The probability density function is shown as below – “μ” is the mean and “σ²” is the variance.

\[
\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right)
\]

The standard normal distribution is “the normal distribution with a mean of zero and a variance of one”(the green curve in Figure 2.4) [32]. From the figure, we can see that in a standard normal distribution, 50% of the values are under the mean and 50% of the values are above the mean.
In Six Sigma approach, “Sigma” is used as a scale for levels of process capability or quality. According to that, “Six Sigma” equates to 3.4 Defects Per Million Opportunities (DPMO) [33, 34]. Therefore, as a metrics, Six Sigma focuses on reducing defects.

Figure 2.5 [35] demonstrates how Six Sigma measures quality. In the figure, if we achieve 68% of aims, then we are at the 1 Sigma level. If we achieve 99.9997% of aims, then we are at the 6σ level which equates to 3.4 DPMO [36]. From this point of view, Sigma level is to show how well the product is performing. It seems this level can never be achieved. However, the Sigma level is not our purpose, the real purpose is to improve quality continually. The higher Sigma level we have reach, the higher quality we get.

2.2.3.1 Sigma Level Calculation

The calculation of Sigma level is based on the number of defects per million opportunities (DPMO). The formula [6] is

$$DPMO = 10^6 \frac{D}{N*O}$$

Where D means the number of defects, N means number of units produced, and O is the number of opportunities per unit. For example, a software company wants to measure their software product’s Sigma level. In their product, there are 200,000 lines of code (LOC). For each LOC, the company performs one check to test the quality. During the testing, 191 defects are detected. Then we have $DPMO = 10^6 \times 191 / (200,000*1) = 955$. From Table 2.2 [4, 37] (a part of DPMP to sigma conversion table, you can find the whole one in Appendix
A [4]), we can find the sigma level is 4.60. You can also find the free calculators on the website [38].

<table>
<thead>
<tr>
<th>DPMO</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,144</td>
<td>4.55</td>
</tr>
<tr>
<td>986</td>
<td>4.60</td>
</tr>
<tr>
<td>816</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Table 2.2 A part of DPMO to sigma conversion table [4, 37].

2.2.4 As a Methodology

Six Sigma approach is not just counting defects in a process or product, but it is a methodology to improve processes. The Six Sigma methodology focuses on [31]:

- Managing the customer requirements.
- Aligning the processes to achieve those requirements.
- Analyzing the data to minimize the variations in those processes.
- Rapid and sustainable improvement to those processes.

When we look at Six Sigma as a methodology, there are many models available for process improvement like DMADV, DMAIC, Breakthrough strategy, Roadmap, New Six Sigma, Eckes method, Six Sigma Roadmap, IDOV, and DMEDI [39]. The most widely used models are DMAIC and DMADV. The DMAIC model is used when a process or product is in existence but is not meeting the customer requirements. And the DMADV model is used when a process or product is not in existence or is needed to be developed [39-42].

2.2.4.1 DMAIC Model

Motorola implemented the first Six Sigma model called as MAIC (Measure, Analyze, Improve and Control). It was developed by Dr. Mikeal Harry. This model was used to solve the already known quality problems [39]. GE, unlike Motorola was unaware of their quality problem. They needed a model that can firstly map the real quality problems and then to solve them. Dr. Mikeal Harry took advantage of his experience at Motorola and developed a new model DMAIC (Define, Measure, Analyze, Improve and Control) see Figure 2.6. Nowadays this model is mostly in Six Sigma implementation. The phases of DMAIC model are explained as follows [39, 40, 43]:

- Define phase is to define the customer’s requirements and their expectations for product or services. To align the project goals with business goals. To define the project scope, the start and stop of the process.
- Measure phase is to develop a data collection plan for the current process. To collect data for the current process and to develop a measurement system. The measurement system is used to calculate the current performance of the process.
- Analyze phase is to find out the gap between the current performance and the goal performance. To analyze the collected data of current process and to determine the main factors of the poor performance. To find out the source of variation in the current process.
- Improve phase is to identify and select the right design solutions to fix the problems. The set of solutions to improve the sigma performance are selected on the basis of root causes identified in Analyze phase.
• Control phase is to finally implement the solutions. To provide the maintenance of
the improved process so that the improved Six Sigma process can run for a long
time.

![Diagram of DMAIC model]

Figure 2.6 Phases of DMAIC model.

2.2.4.2 DMADV Model

DMADV (Define, Measure, Analyze, Design and Verify) model was developed by Thomas
Pyzdekis. This model is applied to the development of new processes or products. The
phases of DMADV are described below [40]:

- Define phase is to find out the customer needs and expectations and to define the
  project scope.
- Measure phase is to identify the CTQs (critical to qualities), process capability and
  risk assessment.
- Analyze phase is to develop the high level design concepts and design alternatives.
  To select the best design.
- Design phase is to develop plans for test verification, this may require simulations.
- Verify phase is to implement the process in operational scale.

2.2.5 As a Management System

Through experience, Motorola has found that using Six Sigma as a metric and as a
methodology are not enough to drive the breakthrough improvements in an organization.
Motorola ensures that Six Sigma metrics and methodology are adopted to improve
opportunities which are directly linked to the business strategy. Now Six Sigma is also
applied as a management system for executing the business strategy.

Six Sigma approach provides a top-down solution to help the organization. It put the
improvement efforts according to the strategy. It prepares the teams to work on the highly
important projects. It drives clarity around the business strategy [31].

2.3 Summary

Nowadays, the quality property of product is becoming much more important than it before.
To examine the quality, we should consider different approaches which include customer,
transcendent-based, product, manufacturing, and product value. Not all approaches shall be
used in one product, but we use different ones in different parts.
Improving quality is not free. It costs a lot of money, time and resources. However, the benefits are also attractive. Not only increasing profits, but also can obtain loyalty, stronger market position and lead time, reduced costs, higher productivity, and more job opportunities. Proper quality improvement does not mean losing money in business, it means future investment.

Software demands high quality. Five approaches should also be considered. Based on those approaches, process improvement is generated to fulfill them. It provides project members a regular method of using the same way to do the same work. Defects found in previous efforts are fixed in the next efforts. One brilliant method is Six Sigma.

Six Sigma approach have been invented for more than two decades. It is successfully and continually used in manufacturing. Now it was spread to many other fields all over the world. Six Sigma approach focuses on process improvement. After it was invented, Six Sigma’s definition has reached three levels – as a metric, as a methodology, and as a management system. As a metric, it aims to reducing defects. The highest level “6σ” equates to 3.4 defects per million opportunities. As a methodology, it focuses on improving process. DMAIC and DMADV models are the most common used. As a management system, it combines the metric and methodologies for executing the business strategy, and aims to continuous improving product quality.
3 Tools and Techniques in Six Sigma

This chapter mainly describes the tools and techniques which are used in Six Sigma process improvement projects. By using those tools and techniques, Six Sigma projects become easier and effective.

3.1 Introduction

Since the Six Sigma approach is invented, many old quality tools are adopted in Six Sigma process improvement project. At the same time, some new specific tools and techniques are introduced. In the chapter, those tools and techniques are distributed in two parts.

The first part is related to the most popular 7 Quality Control (QC) tools. They are Cause-effect Diagram, Pareto Chart, Flow Chart, Histogram, Check Sheet, Control Chart, and Scatter Plot. Those tools are original gathered by Kaoru Ishikawa in 1960s [44-46]. After these years’ evolution and their easy-to-use property, 7 QC tools are applied in every quality improvement projects in various fields. In Six Sigma, they are extensively used in all phases of the improvement methodology (see Figure 3.1 [47]). The functionality of them is described in Section 3.2 in detail.

Another part is a collection of special tools which are frequently used in Six Sigma projects. We also associate them with the five phases of DMAIC methodology (see Figure 3.2 [48]).

3.2 Seven Quality Control Tools

Seven quality control tools frequently used in Six Sigma projects are introduced in the following sections.

3.2.1 Check Sheet

The check sheet is used to collect data of the desired characteristics of a process that should be improved. If the collected data is incorrect, most efficient methods will result in a failure. In Six Sigma methodology it is used in the measure phase. The check sheet is represented in
a tabular form. The check sheet should be simple and aligned with the characteristics that are to be measured [10, 47].

3.2.2 Histogram

Histogram is used in Six Sigma in the analyze phase. It is used to learn about the distribution of the data collected in the measure phase. Often we have huge data and each observation cannot be represented in figure. With the help of histogram the collected data is divided into different classes or intervals. The area of each rectangle in the histogram is proportional to the number of observations within each interval or class. So if we sum the areas of all rectangles it is equal to total number of observations [10, 47].

When applying a histogram there should be at least 50 readings to get a good understandable shape of distribution. The number of intervals or classes should be between 6 and 12. To get the intervals it’s good to take the difference of highest and lowest value in the data. If there are too many or too less data values or intervals then the histogram will be of a flat or peaked shape [10, 47].

3.2.3 Pareto Chart

The Pareto chart was introduced by Joseph M. Juran in 1940s. Juran named it after the Italian statistician and economist Vilfredo Pareto (1848-1923). There are several quality problems to be addressed in a project. Often the problems are solved one by one. The Pareto chart helps in deciding the order of problems in which they should be solved. Pareto chart is related to the 80/20 rule found in business economics. The 80% of problems are because of 20% of causes [10, 47].

In the Six Sigma methodology Pareto chart has two main functions. Firstly in the define phase it helps in the selection of the appropriate problem. Secondly in analyzes phase it helps in identifying the few causes that lead to many problems.

3.2.4 Cause and Effect Diagram

The cause and effect diagram is also known as fishbone diagram or an Ishikawa diagram. It was introduced by Dr Kaoru Ishikawa in 1943, while working in a quality program at Kawasaki Steel Works in Japan [10, 47]. Once we have a quality problem its causes must be found. Cause and effect Diagram helps to find out all the possible causes of an effect (problem). It is the first step in solving a quality problem, by listing all the possible causes. In Six Sigma it is used in the define phase and analyze phase [10, 47, 49].

The reason that Cause and Effect Diagram is also called Fishbone Diagram is that it looks like a skeleton of a fish. The main problem is the head of the fish, the main causes are Ribs and the detailed causes are the small bones.

3.2.5 Stratification

Stratification is used to divide the collected data into subgroups. These subgroups help in finding the special cause of variation in the data. It provides an easy way to analyze the data from different sources in a process. It is used very less as compare to other quality tools but it is beneficial. In the Six Sigma methodology it is used in the improve phase. The collected data is usually stratified in the following groups: machines, material, suppliers, shifts, age and so on. Usually stratification is done in two areas but if the data is large than further stratification is also possible [10, 47].

3.2.6 Scatter plot
Scatter plot is used to define the relationship between two factors. Its main function is to identify the correlation pattern. The correlation pattern helps in understanding the relationship between two factors. In Six Sigma methodology it is used in the improve phase. Once you know the relationship between the factors then the input factor values are set in a way so that the process in improved.

While constructing the Scatter plot the input variable is placed on the x-axis and the output variable is placed on the y-axis. Now the values of the variables are plotted and the scattered points appear on the figure. These points provide the understanding of the variables and the process can be improved. Often there are many variables affecting the process, in this situation a series of scatter plots should be drawn [10, 47].

### 3.2.7 Control chart

The Control chart was introduced by Walter A. Shewhart in 1924. Industry is using Control chart since the Second World War. It is also known as Statistical Process Control (SPC). In Six Sigma methodology it is used in analysis, improve and control phase. In analyze phase Control chart is helpful to identify that the process is predictable or not. In improve phase it identifies the special cause of variation. And in control phase it verifies that the process performance is improved. It shows graphically the outputs from the process in different time intervals.

There are two main purposes of Control chart. First is the creation of a process with a stable variation. The second is to detect the change in the process i.e. alteration in mean value or dispersion.

### 3.3 Special Tools

Any technique which can improve process quality can be a Six Sigma tool. As said in above section, only seven QC tools are not enough for the whole Six Sigma projects. By investigating, we found many other tools which can also significantly help to improve process (Further information is provided in the website: [http://www.isixsigma.com](http://www.isixsigma.com)). Some of they are listed below.

#### 3.3.1 Brainstorming

As defined by Alex Osborn [50], Brainstorming is "a conference technique by which a group attempts to find a solution for a specific problem by amassing all the ideas spontaneously by its members”. It is designed to obtain ideas related to a specific problem as many as possible. It motivates people to generate new ideas based on themselves judgments. If the environment is comfortable and participants feel free to announce their minds, it will produce more creative ideas. To organize an effective and successful brainstorming, you shall follow steps below [51]:

- Define the problem which you want to solve. Only well defined problem could generate the best ideas. In contrast, an unclear defined problem will mislead participants.
- Set down a time limit and an idea limit. Generally the meeting is around 30 minutes to generate 50 to 100 ideas. It depends on the size of groups and the type of problem.
- There should be absolutely no criticism for any ideas. Everyone’s ideas need to be written down even they are such impossible or silly. Try to keep everyone involved to develop ideas, including the quietest members.
- Once upon the limited time is over, select the best five ideas which everyone involved in the brainstorming agreed.
Write down five criteria for judging which idea is the best one for the defined problem.

Give each idea a score of 0 to 5 points which depends on how well the idea meets each criterion. Add up the scores when all ideas have been evaluated.

The idea which gets the highest score is the best solution for the problem. At the same time, the other ideas shall be recorded as the alternatives in case the best one is not workable.

Brainstorming is a great way to generate ideas. During the brainstorming process there is no criticism of ideas which is to motivate people’s creativity. Individual brainstorming can generate many ideas, but it is less effective for each one’s development. This problem can be solved by group brainstorming which tends to produce fewer ideas for further development.

3.3.2 Affinity Diagram

The affinity diagram is developed by Kawakita Jiro [52], so it is also called KJ method. It is used to organize large number of data into logical categories. Generally, we use affinity diagram to refine the ideas generated in brainstorming which is uncertain or need to be clarified. To create an affinity diagram, we need to sort the ideas and move them from the brainstorm into affinity sets, and creating groups of related ideas. Below issues should be followed:

- Group ideas according to their common ground. The reason can be ignored.
- Using questions to clarify those ideas.
- If an idea has several characteristics, we should copy it into more than one affinity set.
- Combine the similar small affinity sets into one, and break down the complex sets.

The final result of affinity diagram shows the relationship between the ideas and the category, which can help brainstorming to evaluate ideas. And it is also considered the best method for the ideas without speaking.

3.3.3 High-Level Process Map (SIPOC Diagram)

SIPOC diagram is a Six Sigma tool which is used to identify all process related elements before we start to work. Predefine those factors can avoid we forget something which may influence the process improvement, especially in complex projects.

SIPOC is the logograms for “Suppliers, Inputs, Processes, Outputs, and Customers”. All your works are to

- Identify suppliers and customers who will influence the projects.
- Obtain the inputs for processes from suppliers.
- Add value through processes.
- Provide outputs to meet customer’s requirements.

3.3.4 Measurement System Analysis (MSA)

Measurement System Analysis (MSA), or called Measurement Capability Analysis (MCA), is used to assess the capability of process measurement systems by using experimental and mathematical methods. The purpose is to improve your measurement system, to ensure the system provides the unbiased results with little variations.

Because every project has the different background, so that needs we modify our measurement system to meet customer’s needs. For example in tolerance measurement, it
can be measured in millimeter, centimeter, decimeter and meter. MSA’s job is to analyze customer’s needs, and select the appropriate measurement scale. Other factors which influence the measurement system are [53, 54]:

- Cycle time
- Cost
- Stability
- Bias
- Linearity
- Response-to-Control (RtC) Variable Correlation and Autocorrelation
- Gage R&R (Repeatability and Reproducibility)

3.3.5 Voice of the Customer (VOC) Method

Voice of the customer method is a process to identify customer’s requirements for high quality product. The customers come from different fields. External customers usually are common customers, suppliers, product users, partners, etc. And internal customers include employees from market department, product development department, and so on.

There are several ways to capture the voice of the customer – individual or group interviews, surveys, observations, customer specifications, complaint logs, etc. Through these methods, we can get the stated or unstated needs from the customer. By assessing and prioritizing those collected requirements, it provides ongoing feedbacks to the organization.

3.3.6 Kano Analysis

Kano analysis is developed by Dr. Noritaki Kano [55], it is a quality tool which help to prioritize customer requirements based on their satisfaction. That is because all identified requirements are not equally importance. The result can help us to rank the requirements and identify the few critical ones which have the highest impact. Furthermore, it can help us to make the decision.

In Kano analysis model, there are three types of customer needs (see Figure 3.3 [56]).

- **Must-Be.** Must-be needs are the requirements that have to be met. The customers believe must-be needs are very basic which even do not have any necessary to discuss. For example, in a bank system, the deposit function and draw-out function are must-be needs.
- **Delighters.** Delighters are the needs which the customers do not expect. When those needs are met, the customers will be very happy. When user login the bank system, there are some bright music played in the background. However, he will still be angry when he cannot find any function related to the deposit. The delighters can only have the effects if and only if the must-be needs are met.
- **One Dimensional.** One-dimensional needs are the ones which need to be discussed and negotiated, such as the price. The customers will be more satisfied when the price falls. But on the other hand, the development company will be much unhappier.
Using Kano Analysis in Six Sigma project to understand customers’ needs can help you to create more value for customers and make them satisfy with your produces and services. Furthermore, priorities of requirements are assessed. This can help the company to figure out what are the customers most concerned which close the relationship with customers [56-59].

3.3.7  The Others

The other methods are seldom used, but still very helpful. They are

- **Project Management Methods** – The project management skills can significantly help the Six Sigma improvement projects, such as project planning, project charter, scheduling, communication, HR management, and project management tools.
- **Failure, Effect and Mode Analysis (FEMA)** – The main work of FEMA is to assess risks and put efforts on controlling and minimizing risks. Before you work with those risks and identify their causes and effects, using flow chart to prioritize them in the timely sequence is a nice choice.
- **Stakeholders Analysis** – Identifying the people who have a stake on the Six Sigma process improvement project. Those people will directly or indirectly influence the projects or results. The ones who are not satisfied will insist to changes.
- **Process Documentation** – Effective, clear, comprehensive process documentation is very helpful for the Six Sigma projects, such as process maps, task instructions, measures, etc.
- **Analysis of Variance (ANOVA)** – It is a collection of statistical models which analyzes the variations presented in the project. It is used to assess the differences between groups of data.
- **Correlation and Regression** – These tools assess the relationships (presence, strength and nature) among variables in process.
- **Design of Experiments (DOE)** – It is used to assess the performance of a process. Generally, it tests two or more characteristics under the different conditions. By comparing, the causes of a problem will be identified. It also can be used to optimize results.

3.4  Summary
There is no a specific tool or technique for one specific phase in Six Sigma. Any tool that is helpful for the process improvement can be applied in Six Sigma project. As mentioned above, seven quality tools are most widely used in all kinds of quality improvement. They are Cause-effect Diagram, Pareto Chart, Flow Chart, Histogram, Check Sheet, Control Chart, and Scatter Plot. The other special tools are gathered from successful Six Sigma cases which include Brainstorming, Affinity Diagramming, SIPOC Diagram, MSA, VOC Method, Kano Analysis, and so on.

Tools are tools. Using the proper one in the right place is the key factor which influences success. How to control such great power demands the understanding and familiarity of tools and techniques. That is why we need the help from specialists. The detail of how to control Six Sigma is presented in the next chapter.
4 SIX SIGMA IN MANUFACTURING

This chapter firstly analyzes the corporate framework of Six Sigma in manufacturing from academic view. After that, successful experiences from Company 1 and ABB are described. The aim is to identify what is the condition of Six Sigma in manufacturing. And it will help us to implement Six Sigma in software.

4.1 Manufacturing Corporate Framework

The corporate framework of Six Sigma has been launched by Motorola for many years. Lots of companies like GE, ABB, and AlliedSignal have enlarged during the implementation. Nowadays Six Sigma approach has become more pragmatic [60].

In [47], Magnusson and his copartners have make a comprehensive and deep analysis with this corporate framework. Figure 4.1 shows that there are four factors and one methodology (DMAIC) within the framework. Four factors are top management commitment, stakeholder involvement, training scheme, measurement system. Among them, top management commitment and stakeholder involvement is the base of the framework. Without them, the other factors and methodology are meaningless. All four factors support the core methodology which is used in every improvement projects [47, 61, 62].

![Figure 4.1 The corporate framework for Six Sigma [47].](image)

4.1.1 Top Management Commitment

Top management commitment can be break down into three parts – top management, personal belief and commitment, and set a tough goal. Below we will discuss them separately.

- **Top management** – For a company, implementing Six Sigma is a strategic decision which aim to save cost and increase revenue. It needs to be taken by top management. Actually in many companies, Six Sigma is given the top priority [60]. The members of top management generally are the company owners, project sponsors and advocates. Those people shall be open-mind and hear the Six Sigma report frequently [47].

- **Commitment** – Top management needs a high degree of personal belief and commitment. When launching Six Sigma, any confusion or doubts about the top management will slow down the progress. Just like John F. Welch (CEO of GE) have said in his speech at the GE 1996 Annual Meeting in Charlottesville [47], “… we have selected, trained and put in place the key people to lead this Six Sigma effort, … we have the balance sheet that will permit us to spend whatever is requirement to get to our goal” and “… the return on this investment will be enormous”.


- **Set a tough goal** – It is the responsibility of top management. A clear goal can motivate people and lead them to success. At the same time, the tough goal should be achievable. Some companies set their goal for process performance to 3.4 DPMO (equals to 6σ). That is not impossible, but we can set it more intelligently. For example, we set the goal to reduce DPMO by 50% for each year. In reality this number is even higher. ABB have set the goal to be 68% for a yearly reduction, while GE’s goal is 80% [63].

From all above, we can say top management commitment is to select the right person to lead the Six Sigma effort, trust them and support their decisions, and set a smart tough goal which improves process performance continuously.

### 4.1.2 Stakeholder Involvement

Only top management commitment is not enough to reach the goal which is set for improving process performance. The companies also need stakeholders’ help. Stakeholders are people or organizations who will be affected by the product and who have a direct or indirect influence on the product [64]. Stakeholder involvement is to show the improvement methodology and tools of Six Sigma to stakeholders and get their support. The stakeholders can be employees, suppliers, customers, etc.

Stakeholder involvement can shorten the distance of companies with their suppliers and customers. They could give many precious opinions from their view, and these opinions can help to improve process performance or modify our Six Sigma activities. Supplier involvement is essential. That is because the variation in their products will be transferred to the company’s processes. Sharing the Six Sigma information and process performance data can help them to improve their product quality, which indirectly improves the company’s process. The Six Sigma can only become the success when tied with customers. They shall be allowed to join the process improvement, share the responsibility. Later on, they will be happy and proud since they are involved [47].

However, training for stakeholders is necessary. Some courses can help them to understand process improvement and Six Sigma comprehensively. And that can also help to improve their processes [47].

### 4.1.3 Training Scheme

Training in Six Sigma includes the knowledge of process performance, methodology, statistical tools, deployment, frameworks, etc. The experience from Motorola, GE, Dow Chemical, etc has proved the training can extremely be cost saving. In Motorola, the reported return on investment ratio was 29:1. In GE, the investment on Six Sigma increased from US$ 250 million in 1996 to US$ 450 million in 1998. They believe the high investment in Six Sigma training is towards to a rapid revenue growth and cost reductions [60].

Figure 4.2 [47] demonstrates the Six Sigma training scheme. From the figure, we can see that there are five roles in Six Sigma – White Belts, Green Belts, Black Belts, Master Black Belts and Champions. According to the roles, Six Sigma training courses are divided into three levels – Basic level for White Belts, Medium level for Green Belts and Comprehensive level for Black Belts. In some companies, they have Yellow Belts between White Belts and Green Belts [63]:

- **The Basic level course for White Belt** – provides a basic introduction of Six Sigma including some basic experiments, variations introduction, cost of poor quality, etc. Generally, it only spends one day and is offered to front-line employees.
- **The Medium level course for Green Belt** – is the advanced version of Basic level. The participants are selected to learn some Six Sigma tools, measurement, process management, and how to use improvement methodology in the real projects.
- Comprehensive level course for Black Belt – is more comprehensive and aims to create full-time improvement experts. In the course, the participants are required to perform an improvement project to save a specific cost.
- Two additional course – Six Sigma engineering and Six Sigma management focus on process design and interaction management separately (The content of all five courses are described in Appendix B [47]).

<table>
<thead>
<tr>
<th>Course levels</th>
<th>Roles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Champion</td>
</tr>
<tr>
<td></td>
<td>Master Black Belt</td>
</tr>
<tr>
<td>Comprehensive</td>
<td>Black Belt</td>
</tr>
<tr>
<td>Medium</td>
<td>Green Belt</td>
</tr>
<tr>
<td>Basic</td>
<td>White Belt</td>
</tr>
</tbody>
</table>

Figure 4.2 The Six Sigma training scheme with course levels and roles [47].

Two other roles are Master Black Belts and Champions. Master Black Belts are selected from the people who have Black Belt qualifications. Their job is to teach Six Sigma courses within Six Sigma training scheme. Champions who are on the top of organizations drive the whole process. Those people have extra experienced knowledge of Six Sigma, take part in selections of improvement projects, and make decisions.

The number of people play different roles depends on the size of company. For example, in a 2,000 employees company, it should have one Master Black Belt at least. There should be 20 Black Belts for every Master Black Belt and 20 Green Belts for every Black Belts [47].

### 4.1.4 Measurement System

Measuring process performance can help us to identify problems from poor process performance, which is good at solving problems in the early stage. A simply metric – DPMO (Defects Per Million Opportunities) – is used to evaluate the variation in critical-to-customer characteristics of processes and products [47, 65].

There are two types of characteristics that can be included in the measurement system – continuous characteristics and discrete characteristics. Discrete characteristics are number-related, which provides attribute data. Generally, most of observations are applied for it. Measuring continuous characteristics can provide continuous data which could assist all observations. Although two types of characteristics are measured and analyzed differently, the results shall be combined into one number (the average of all individual characteristic results) for the whole company’s process performance. This combined DPMO value is simple and easy, and it can make the attention of whole company on the process performance.

### 4.2 Improvement Methodology
After the foundation is settled, a specific Six Sigma project can be started. Six Sigma approach provides a formalized improvement methodology – DMAIC model which we have briefly introduced in Section 2.2.4.1. This model starts with a define phase, and other four specific phases are followed – measure, analysis, improve, and control (See Figure 2.6).

4.2.1 Define

This phase is to select the proper improvement projects and identify process to be improved. One of most valuable source is Six Sigma measurement system. The DPMO value has indicated the poor performance process. Other valuable sources are customer complaints, competitor analysis, employee suggestions, etc. In general, only poor performance processes or characteristics need improvement. Otherwise, the whole product shall be improved. Among a number of potential improvement projects, the Pareto chart and the cause-effect diagram can be used for prioritization. The criteria are [47, 66]:

- Benefits for customers.
- Benefits for company.
- The complexity of the process.
- Cost saving potential.

With the help of above criteria and statistical tools, a characteristic or process will be identified for improvement. At the same time, a team shall be organized for the improvement project. In this team, a project sponsor from top management shall be appointed, which is to ensure that the project gets top management’s focus. Other members like Black Belts who is responsible for management and making decision, Green Belts and White Belts who assist Black Belts’ work. It is obviously that all the team members shall have a great understanding with Six Sigma. Several Six Sigma training courses are essential.

4.2.2 Measure

There are mainly two jobs in measure phase. The first one is to assist define phase for improvement project selection. Before the improvement project is defined, several characteristics or processes shall be measured. Most of Six Sigma companies apply the mental model (i.e. ‘Y is a function of X’). Y is selected from variation results through Six Sigma measurement system, while X factors which influence Y need to be identified for each Ys. The relationship is demonstrated in Figure 4.3.

![Figure 4.3 Relationships between Ys and Xs.](image-url)

The other job of the measure phase is to collect the data for the selected Ys and Xs. Before the selection decision is made, related data such as types, sizes, measurement intervals, and how to record the data are needed. Be different with the measurement of process performance, measurement of Ys and Xs are more detailed and project related.

4.2.3 Analyze
Analyze phase assesses the data which is collected for Ys and Xs. By assessment, the performance of Ys can be calculated in terms of DPMO values or sigma values. After comparing those values, similar processes can be discerned. Based on those analyses, a goal for improvement can be set.

4.2.4 Improve

All of activities within improve phase are included in Figure 4.4 [47]. It starts from deciding if the selected Y or Ys need to be improved. Then we need to identify and measure Xs which associate with the decided Y or Ys. A group of statistical tools and experiments are applied to find out the improvement opportunities. We can also identify the special causes for variations among the Xs. If the result is that those variations can be improved, then they should be removed or their impacts reduced. On the other hand, if there are no special causes which are identified or those variations cannot be improved, we shall reapply statistical tools and redesign experiments. If the results do not change after several iterative, we shall consider that might be the design problems of process or product. Then, the process or product is designed with the aim of improvement.

![Figure 4.4 The flow of activities in improvement phase [47].](image)

4.2.5 Control

There are also two activities in control phase. After improvement phase has been carried out, the planned improvements shall be verified. Improper or incorrect improvements will be discovered and corrected in the next improvement project. Control Chart and DPMO Track Chart are highly recommended to verify the long-term effects of improvements.

Another important activity in this phase is to formalize the results. The results which only match a single process or product will be reorganized and reanalyzed to match the whole company. Both successful and failed cases shall be formalized, reported and stored. The companies should gain experience from those cases for further improvements. Based on that,
a guideline shall be established. And that will be very helpful for the future Six Sigma projects. Every company shall create their own Six Sigma project guideline [47, 61, 66].

4.3 Ten Tips from ABB

ABB is a Swiss-Swedish technology company which has 160,000 employees in more than 100 countries. Its products and services cover five fields – Power Transmission and Distribution; Automation; Oil, Gas and Petrochemicals; Building Technologies; and Financial Services. To have an additional cost reduction and cycle time reduction, ABB starts to apply Six Sigma from 1993 with the help from Motorola. Since the first Black Belt course was held in 1994, Six Sigma is now mandatory in the most parts of ABB and has spread to all parts [47, 60, 66].

15 years’ application for Six Sigma at ABB generates very precious and successful experiences. Magnusson and his partners has summarized ten secrets of success from ABB in [47]:

- **Endurance** – The key roles involved in Six Sigma project should be enduring. If they give up, the Six Sigma projects will never be completed whatever it is long-term or short-term. The key roles include: the top believer – CEO, the top driver – Champion, and the top improvement expert – Black Belts.
- **Early cost reductions** – Launching the early Six Sigma improvement projects can bring confidence and determination. That is because the results and experiences of those completed projects are shared in the organization. They can also provide successful cases for Black Belt courses.
- **Top management commitment** – Six Sigma is a strategic which needs the top management’s support. A successful Six Sigma project requires dedicated time, attentions and resources from top management to achieve the goals.
- **Voluntary basis** – Six Sigma aims to continuous improvement which may last a long term. So that the Six Sigma cannot be forced to deploy to employees.
- **Demanding Black Belt course** – In Six Sigma improvement projects, Black Belts play an expert role that need to lead and manage the progress of projects. Black Belts course is a vehicle for brings the Six Sigma approach into the company. In training Black Belts, the courses play a very significant role.
- **Full-time Black Belts** – Compared with part-time Black Belts, full-time Black Belts has enough time and attentions to carry out and follow up improvement projects.
- **Active involvement of middle managers** – It is a fact that most of Black Belts come from the middle managers. That is because the middle managers have the good enough background to learn Black Belts courses. At the same time, they can broaden their improvement perspectives and have the ability to follow the improvement projects.
- **Measurements not enough** – Only the measurement in Six Sigma improvement methodology is not enough, it cannot provide enough information for process improvement. It should work with the measurement system in organization intelligently.
- **One metric and one number** – By using one metric for process performance and generating one number for performance, Six Sigma can effectively motivate all improvement work. Because people do not like change, and always satisfy their current status. The metric and the number will show if the process is as good as they think.
- **Factorial experiments** – Using factorial experiments alone or combined with statistical tools can significantly help us to identify the causes of variations.
4.4 Summary

Six Sigma approach has been successfully applied in manufacturing for two decades. From those success experiences, a successful Six Sigma project must base on at least four foundational activities. They ensure the progress of projects from top management to human resources. They are

- Top management commitment – The Six Sigma projects shall obtain top management’s completely trust and support. There should be a person in top management who is responsible for the whole improvement project.
- Stakeholder involvement – Whatever the project is small or large, there is a necessary to involve the related key stakeholders and get their support. This can help to shorten the distance between company and its customers.
- Training scheme – A well-designed training system can continuous cultivate talented people for Six Sigma projects.
- Measurement system – To identify the problems which will be improved by Six Sigma projects, we need a measurement system. The combined DPMO value which generated by this system is the only scale for process performance.

When the foundation is well settled, a specific Six Sigma project can be started. From the successful cases, some models can be borrowed to help us to run the project. DMAIC model is a formalized improvement methodology which is the most popular one from successful cases. It contains five phases – define, measure, analyze, improve, control.

- Define phase – select the process, identify the problems and define project scope.
- Measure phase – measure the selected process and collect data.
- Analyze phase – analyze the collected data and identify the gap between the current performance and the goal performance.
- Improve phase – develop the solution and improve the process performance.
- Control phase – maintain the improved process to keep a long-term run.

Each phase has a clear defined aim and an outcome. It is not very hard to follow this sequence and achieve the project goal.

In the last of this chapter, the successful experience from ABB provides some tips which can help us to build the foundation framework and run the Six Sigma project.
5 THE ACCEPTANCE AND MOTIVATION OF SIX SIGMA IN SOFTWARE COMPANIES

This chapter discusses the different views on applying Six Sigma in Software companies and the differences between manufacturing and software processes. Furthermore two questions are addressed. First one is the acceptance of Six Sigma in software companies. Second one is why software companies should adopt Six Sigma approach.

5.1 Different Views on Applying Six Sigma in Software Companies

Since Six Sigma approach was successfully applied to manufacturing industry for more than two decades, it is considered as a new star in the world of quality [67, 68]. There is a common misconception that Six Sigma is only applicable for manufacturing industry. The application of Six Sigma in software companies has faced many controversies. There are many different views on applying Six Sigma in software companies.

5.1.1 Binder’s View

Binder has pointed out three main difficulties. Based on the three difficulties, Binder claimed that [33] Six Sigma is not applicable in software companies. The three difficulties are:

- **Processes** - Software processes are fuzzy as compare to the manufacturing processes. So the application of Six Sigma is easily established and documented in manufacturing, not in software.
- **Characteristics** - There are difficulties in meaningful measurements of software characteristics. Software cannot be measured as weight, distance, width, etc. Total number of faults cannot be measured in software.
- **Uniqueness** - Manufacturing products are generally mass produced but software products are one-off.

Binder’s view is doubtable because only on the basis of three differences, he denied the applicability of Six Sigma in software. In order to identify the real situation, we need a comprehensive understanding about the differences between manufacturing and software.

5.1.2 Two Misconceptions Debunked by Tayntor

Managers cannot deny the importance of reducing defects, increasing customer satisfaction and operating more efficiently. Many software companies are now adopting Six Sigma [6, 8, 69]. Claimed by Tayntor [4], there are two misconceptions associated with Six Sigma in software companies. The first is that, Six Sigma is a statistical analysis, so it is applicable for manufacturing and engineering processes and it has very little or no relevance to software. The second is that Six Sigma cannot be adopted in just a few areas of the company. It should be applied to the entire company. Both these misconceptions should be debunked.

5.1.2.1 Six Sigma Has No Relevance in Software

There is some misconception that Six Sigma applies to manufacturing processes but not to software. The truth is that the tools and techniques of Six Sigma can help software companies by ensuring that the “three rights” are in place [4].
• *The right people are involved* – Many software projects fail because of poor requirements. Poor requirements are caused because all stakeholders are not represented or they participate very late in defining the requirements. Six Sigma approach solves this problem by focusing on teamwork and clearly identifying the customer’s requirements.

• *The right problem is solved* – Six Sigma tools not just clearly identify the customer’s requirements but also impact on the proposed solution. Proper use of Six Sigma tools helps in focusing on the high value system components.

• *The right method is employed* – Six Sigma tools helps the software companies by evaluation the processes and finding the variation in them, finding the causes of defects and ways to prevent them. Example if a project is over budget Six Sigma techniques finds out the main causes and the ways to correct them.

5.1.2.2 Six Sigma Is Applied in Whole Company

The second misconception is that the Six Sigma is only helpful if the whole software company has adopted it. This is a fact that it is easier for a software company to implement Six Sigma if the whole company adopts its philosophy. But there are benefits of adopting Six Sigma tools and incorporating the processes into software development, even if the whole company is not using Six Sigma [4]. Chapter 5 describes the tools and techniques that can improve various aspects of software development.

So Six Sigma has applicability to software companies. The reasons for adopting Six Sigma are clear – fewer defects, faster delivery and increased customer satisfaction [4].

5.1.3 Cost Misunderstanding

There is a misconception that designing a system to Six Sigma is very expensive [36]. Since Six Sigma focuses on the quality from the beginning of a project so it has minimal cost to improve quality. On the other hand if we wait up to the testing phase in finding the defects then the cost to fix the defects is very high. A cost and benefit analysis should be done in the Six Sigma program to determine the actual gains.

5.2 Software versus Manufacturing

Six Sigma approach has brought large number of profit to manufacturing by improving product quality. However, the differences between software and manufacturing make it hard to apply Six Sigma directly to software. Identifying these differences can help us to solve this problem.

5.2.1 The Differences between Software and Manufacturing

<table>
<thead>
<tr>
<th>Software Product</th>
<th>Manufacturing Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>It has logical components.</td>
<td>It has physical components.</td>
</tr>
<tr>
<td>It has no material existence and has no physical properties.</td>
<td>It has physical properties i.e. color, mass etc.</td>
</tr>
<tr>
<td>It do not have any link with the physical laws i.e. Newton’s laws.</td>
<td>It obeys physical laws.</td>
</tr>
</tbody>
</table>
Table 5.1 Differences between software and manufacturing products [34, 36, 67, 70].

<table>
<thead>
<tr>
<th>Software Process</th>
<th>Manufacturing Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input is customer requirements, skills, tools etc.</td>
<td>Input is raw material. Raw materials do not have much variation in quality.</td>
</tr>
<tr>
<td>It is not visible. It is made visible through documentation, i.e. Data flow diagrams, flowcharts, entity relationship diagrams, decision trees, decision tables, use case diagrams, object oriented models etc.</td>
<td>It is visible.</td>
</tr>
<tr>
<td>All software characteristics cannot be measured on continuous scale. In most cases the output is either correct or wrong. Software has fault tolerance to increase reliability. It is usually done by putting redundant modules.</td>
<td>It has design tolerance. Design tolerance means the maximum range of variation in which the manufactured part can work.</td>
</tr>
<tr>
<td>It is difficult to predict the behavior of a software process, due to changes in requirements and technology changes.</td>
<td>It is easy to predict the behavior of a manufacturing process.</td>
</tr>
<tr>
<td>In software productivity the most important factor is human intelligence.</td>
<td>The manufacturing productivity is most of the times machine intensive.</td>
</tr>
<tr>
<td>The external factors that may affect a software process are programming skills, level of expertise, knowledge of developer and customer, tool and technologies that are used.</td>
<td>The external factors that may affect a manufacturing process are temperature, humidity, machine performance etc.</td>
</tr>
<tr>
<td>The process variation in a software process is due to differences of skills and experience of one developer to another.</td>
<td>The process variation in a manufacturing process is due to difference between components.</td>
</tr>
<tr>
<td>Technology in software processes changes very fast.</td>
<td>Technology in a manufacturing process changes very slow.</td>
</tr>
</tbody>
</table>

Table 5.2 Differences between software and manufacturing process [36, 67, 70-72].

The differences are demonstrated in following points [36, 67, 73]:

- **Non repetitiveness** - Once software is developed, it can be reproduced into millions of identical copies. This is the reason why software developers focus on the development process unlike manufacturing process where the focus is on the reproduction of the identical copies.
- **Input and output** - Unlike manufacturing process the inputs and outputs are different in each software process. Each software process deals with different set of user requirements.
- **Cognition** - In software development the transformation of user requirements to a module is cognitive intensive. On the other hand manufacturing activities are targeted to minimize cognition.
- **Visualization** - Software development is an intellectual process, before the implementation of Six Sigma it needs to be visualized. This visualization is done by documentation. To find the data relationships, tools are used i.e. data flow diagrams, entity relationship diagrams and object models.
- **External Factors** - The external factors in a manufacturing process are temperature, relative humidity, human interaction, machine performance. None of these factors affect software development processes. In software development processes the external factors are programming skills, level of expertise, knowledge, etc.

These differences do not mean that Six Sigma is only applicable to manufacturing. If we know these differences very clearly and be careful about them when applying Six Sigma in software, then those differences are not difficulties. Actually Six Sigma is applicable to software companies. For example Motorola is using Six Sigma in his software department for many years and Tata consultancy Services has gain lots of profits after applying Six Sigma [8, 36].

### 5.3 Why Software Companies Choose Six Sigma Approach?

After the above discussion there is a question that does Six Sigma make sense in software companies. The answer is yes, Six Sigma is good for software companies especially for the following situations [36, 74, 75].

- **Legal Responsibility** – Six Sigma approach helps to fulfill the legal responsibility. Now-a-days if something goes wrong people go to the lawyers according to Human Rights Act. Up to now disasters are not blamed on software’s but software’s can cause huge disasters. Software has many identical copies. These copies are installed in different companies. If there is some defect in the software then all the companies are at great risk of failure. Even the most powerful companies like Microsoft are fearful to such failures.
- **Mission Critical Systems** – Now a day’s software’s are developing for mission critical systems. The failure of a mission critical results in a great loss to society. Here comes Six Sigma which means 3.4 defects per million opportunities, it can prevent the software from failing. In 1988, American Airlines lost 59 million dollars in ticket sales. The problem was the discount ticket was mistakenly blocked in the ticket reservation system. As a result travelers moved to their competitors. These weaknesses can be removed by Applying Six Sigma which provides near defect free performance.
- **Complex Systems** – The application of Six Sigma is very effective in case of complex systems. For example there a complex system with like 1000 modules if all the parts are designed according to Six Sigma than there is a higher probability of getting a defect free system.
- **Software Company** – Software companies have a bad reputation of buggy and late. Today software size is very large like more than thousands of lines. It has more probability of having many defects. In this situation Six Sigma can help us to get a near defect free product.
According to a survey conducted in software companies by [67], the following results are found. Most software companies have completed five to ten Six Sigma projects and their bottom-line saving per project is over £100k on average. In most companies the Six Sigma level varies from 2.54 to 4 Sigma. The following criteria were used by most companies in survey to find the success of Six Sigma.

- Impact on bottom-line
- Reduction of defect rate.
- Reduction in cost of poor quality.
- Improvement in a process.
- Reduction in customer complaints.

5.4 Summary

Can Six Sigma approach be applied in software? This question has been discussed many years before. At the beginning, lots of people think it is impossible to combine them, like Robert Binder. From his point of view [33], software and manufacturing are totally two different fields. At least three difficulties cannot be solved. Firstly, software process is not as simple as manufacturing process. Manufacturing process is a repetitive thing. The more familiar with the process, the higher productivity is obtained. In software, each project is unique, either with the processes. So the application of Six Sigma is hard to be established. The second one is about the product characteristics. Manufacturing product can easily be measured as weight, distance, width, etc. For software product, the software characteristics such as defects number, Mean Time Between Failure (MTBF), usability cannot be simply measured. The last one is the uniqueness. As we said before, each software product is unique. But in manufacturing, all products which are produced by a same product line shall have the same quality, standard, shape and function.

However, Christine Tayntor [4] have the different idea. He thinks that is our misconceptions. Six Sigma approach can be applied in software companies if we involve the right people, solving the right problem, and using the right method. At the same time, although using Six Sigma approach for process improvement costs a lot, it worth. Few defects, faster delivery and increased customer satisfaction will generate more potential profits than you think.

The differences between software and manufacturing are obvious and unavoidable. The main distinct factors of software are non-repetitiveness, unique input and output, cognition, visualization, and some external factors such as employee’s skill and knowledge. These differences are reflected on the software product and software process.

Although many people keep the deny opinion and there do have many differences between software and manufacturing, we still think applying Six Sigma approach in software companies is beneficial. Firstly, all deny opinions and misconceptions are built on the misunderstanding of Six Sigma approach and unfamiliar with the software. Secondly, we never say applying Six Sigma approach in software is just the copy of manufacturing’s method. The differences do exist. According to them, we need to modify the Six Sigma approach, as the same time with the software process. Change them to fit for software’s situation. And that demands further research and more experiments. Thirdly, the principle of Six Sigma approach is close with what is in software. It can help software companies to reduce defects, improve quality, increase customer’s satisfaction, and enhance market-share. That is also the answer of why software companies choose Six Sigma, especially for complex systems, mission critical systems, and legal responsibility.
6 INTERVIEWS CASE STUDY AND CASES STUDY REVIEWS

This chapter presents two interviews, a case study and three case studies are reviewed. The chapter indicates the start-of-art of Six Sigma approach.

6.1 Interview 1

The motivation behind the interview 1 is to understand how Six Sigma is implemented in manufacturing. Later this will help to propose steps for Six Sigma implementation in software's.

6.1.1 Introduction of Company

Company 1 was established in 1973 in China. As a manufacturer of key electronic components, it has grown into one of the industry leaders. In today's fast-paced business environment, company's management is determined to become the world's top electronics parts maker by selectively concentrating resources on constant quality improvement and advanced technology development. The Six Sigma initiative is followed to achieve the highest quality possible in all operations, from initial stages of product development. The ultimate goal is to streamline operations by implementing a global supply chain management system and online procurement and sales[76].

6.1.2 Introduction of Interviewee

The interviewee is working in Six Sigma department as a Six Sigma Green Belt for three years. She has participated in several production process improvement projects and has a great understanding with how to implementing Six Sigma for quality improvement in manufacturing.

6.1.3 Interview Execution

A questionnaire was designed to conduct the interview. The questionnaire was consisted of both open-ended and closed-ended questions. Furthermore the questionnaire was tested and validated by the authors in order to eliminate the conclusion validity threat. For the complete questionnaire see Appendix C.

The interview is conducted by the authors. As training and experience plays an important role in conducting an interview. So the authors had enough interviewing experience and training by studying different courses during their Master’s study.

Before the interview was conducted, the thesis related information was provided to the interviewee. This helped the interviewee to get the background knowledge of the thesis. The interviewee was provided sufficient time to answer the questions.

6.1.4 Interview Analysis

In Company 1, there is a special department which is responsible for directing Six Sigma projects. Two kinds of characters are involved in this department – Black Belts and Green Belts. Both of them are full-time work. And also in middle management, 80% of managers have took Six Sigma courses, 40% of them have got the Green Belt certification. Company’s aim is to raise the percent up to 100%. Furthermore the Interviewee Y has provided a real
Six Sigma case study to answer the questions related to DMAIC method. The case study is described in the below section.

6.1.5  A Real Six Sigma Case Study

Among several cases we have gotten, the project xxx attracted most of authors’ attention, which is related to CUTTING machine improvement. This Six Sigma project has last 3 months and it is extremely according to DMAIC model. And a number of Six Sigma tools are used to help the progress of project.

6.1.5.1  Define Phase

The main reason which leads to improvement is that the product has a high yield (9 million per month) with a low quality. The defects highly reach to 54420 PPM (parts per million). The SAP data from August to October has shown that the main cause of the low quality situation is because of part D (see Table 6.1). By identification, the source of problems is the CUTTING machine.

After the problems are identified, we can develop a Project Charter (see Appendix E) which includes overall commitment, such as Champion, Black Belt, and project team. Other information shall be involved too: project purpose, problem description, customer, goal statement, project scope & plan, project benefits, team selected, schedule, etc.

<table>
<thead>
<tr>
<th>Group text</th>
<th>Good Qty</th>
<th>Defects Qty</th>
<th>Defects Number (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13958447</td>
<td>42122</td>
<td>3009</td>
</tr>
<tr>
<td>B</td>
<td>30249063</td>
<td>6145</td>
<td>203</td>
</tr>
<tr>
<td>C</td>
<td>25534200</td>
<td>1448855</td>
<td>53695</td>
</tr>
<tr>
<td>D</td>
<td>23286000</td>
<td>1267213</td>
<td>54420</td>
</tr>
</tbody>
</table>

Table 6.1 SAP data from August to October in SEM.

6.1.5.2  Measure Phase

In this phase, the causes of product defects are measured by using quality tools. In Figure 6.1, the main problem and its causes are demonstrated (Y’s and X’s). From that we can discover all the related factors. However, which factor has a stronger influence cannot be measured according to this figure.
Figure 6.1 Process Mapping for Company 1 Six Sigma project.

Using XY Matrix can help to prioritize the causes. Furthermore, it can help to figure out which factors or Xs need to be put efforts for improving. In Figure 6.2, the top six Xs of project xxx are calculated. They are:

- Conveyor Belt’s work is not accurate.
- The problem of CUTTING machine’s blade.
- The orientation of CUTTING JIG is not accurate.
- The orientation of material JIG is not accurate.
- Operation standards need to be perfected.
- Benchmarks are not clear which need to be unified.
These factors are the main causes which lead to defects. After we figure out the main causes, the related analysis for each cause can be processed. And also the specific improving method will be generated.

### Analysis Phase

In this phase, six Xs are analyzed separately by using statistic and mathematic methods. Several analysis tools are used, such as 2-Proportion, regression analysis, Two-Sample Test, Kruskal-Wallis Test, etc. By analyzing, the sources of those Xs are identified. For example, the main cause of “Conveyor Belt’s work is not accurate” is because the position of conveyor belt. The higher position generates a lower defects number. “The problem of CUTTING machine’s blade” is related to CUTTING machine’s running time. “Benchmarks are not clear” needs the unification of benchmarks and the training for operators.

The analysis phase not only requires that the Six Sigma team is familiar with the production processes, but also they need the feedbacks from the actual operators. This is a solid process,
because some problems are hard to be identified. Statistic tool can be a good assistant. The whole analysis phase needs all team members to be careful and patient.

6.1.5.4 Improve phase

In the beginning of this phase, some CUTTING related experiences are designed and implemented. The aim of those experiences is to find an optimal solution. For example, we take an experiment to identify the influence of three factors – blade running cycle, blade running temperature, and JIG temperature. The result shows that the blade running cycle owns the greatest influence (see Figure 6.3). Within the situation which is measured in experience, the optimal solution is to set running cycle equals to 5.3 days, blade temperature equals to 120°C, and JIG temperature equals to 80°C.

<table>
<thead>
<tr>
<th>Defects number</th>
<th>Blade running cycle</th>
<th>Blade temperature</th>
<th>JIG temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targ: 10.0</td>
<td>7.0</td>
<td>150.0</td>
<td>100.0</td>
</tr>
<tr>
<td>y = 10.0</td>
<td>[5.3026]</td>
<td>[120.0071]</td>
<td>[80.0089]</td>
</tr>
<tr>
<td>d = 1.0000</td>
<td>5.0</td>
<td>120.0</td>
<td>80.0</td>
</tr>
</tbody>
</table>

Figure 6.3 Defects influence experience of three factors.

Experiment can help me to testify the possible situations, and discover the optimal solution. It’s a very good way to examine the result before we apply. All six Xs have been improved by different method. Figure 6.4 shows the change of appearance validation tools improvement.

Figure 6.4 Appearance validation tools improvement.

In Figure 6.5, the total number of defects is 1238467 from August to October. After the improvement, it reduces to 170397. The decrease percentage highly reaches to 86.34%. This result shows the improvement activities can significant reduce the defect number.
In this phase, firstly experiences are designed and applied to verify the proposed changes. The optimal solution is selected. Then the proposed changes are implemented. In the end, the effect of changes is calculated by tools. This is very valuable for future analysis.

6.1.5.5 Control Phase

Before the Six Sigma project is terminated, a control strategy is developed which is used to avoid the same problem happen. In this project, several approaches are defined as the control strategy:

- Enhance operator’s sense of quality.
- Conduct more training about standard operation.
- Improve CUTTING machine’s automation ability.

After the strategy is defined, the Six Sigma project needs to be terminated. A terminate report is generated which contains the project terminate information, sigma calculation, and benefit estimation (see Appendix E). It is directly reported to the top management.

6.1.6 Case Summary

In Company 1, DMAIC model is their main process improvement methodology. Activities in each phase are clearly defined and are strictly executed. Proper tools and techniques are used to help the improvement, especially for XY matrix which is used in measure phase. It helps to find the sources of problems. After improvement, the final result is just what we expect. This case has improved the Six Sigma approach can significantly help manufacturing to improve process and finally improve product quality.

6.2 Interview 2

The motivation behind interview 2 is to analyze how Six Sigma in implemented in software’s. With the help of it we will propose steps for implementing Six Sigma in software’s.

6.2.1 Introduction to Company

Company 2 is a well know Swedish organization. It is recognized as the world’s foremost provider of information solutions in aviation. Its portfolio includes: worldwide flight information, flight operations services, international trip planning services, aviation weather services and aviation training systems. Through technical customer support, material
management, maintenance services, fleet enhancements and flight operations, the organization provides products, services and integrated solutions to 900 airlines and 150 Maintenance, Repair and Overhaul facilities worldwide.

6.2.2 Introduction of Interviewee

The interviewee is working as a director of quality. He has been working with software development for last 20 years. He has an experience of developer, researcher, project manager and line manager. His educational background is PhD. Furthermore he has received green belt and black belt Six Sigma training from the company.

6.2.3 Interview Execution

A questionnaire was designed to conduct the interview. The questionnaire was consisted of both open-ended and closed-ended questions. Furthermore the questionnaire was tested and validated by the authors in order to eliminate the conclusion validity threat. For the complete questionnaire see Appendix D.

The interview is conducted by the authors. As training and experience plays an important role in conducting an interview. So the authors had enough interviewing experience and training by studying different courses during their Master’s study.

Before the interview was conducted, the thesis related information was provided to the interviewee. This helped the interviewee to get the background knowledge of the thesis. The interviewee was provided sufficient time to answer the questions.

6.2.4 Interview Analysis

The motivation behind the interview was to understand the implementation of Six Sigma in a software company. There following sections describes the implementation of Six Sigma in a software company.

6.2.5 Organization structure

In the company A the plan was to make Six Sigma an integral part of every department. There was no separate department especially for Six Sigma. Two heads were working in the quality department for the implementation of Six Sigma. Out of which one had black belt training and the other had green belt training. Green belt training was provided for all candidates from all departments. The quality department was to coordinate the improvement work. More specifically, the quality department (consisting of two heads) had the mission to contribute to the business success of the Company by increasing the effectiveness and efficiency of the Group’s operating units. They improved, renewed, and created means to control the business processes that delivered explicit value to the clients. They provided an impartial change management consulting resource to the Company, where they acted both as solution consultants, as well as facilitators, in change projects. Central placement within the Company gave them a high degree of organizational impartiality and strengthened their ability to work cross-functionally.

6.2.6 DMAIC Phases

6.2.6.1 Define Phase

In define phase the focus was on processes that needed improvements. A process would qualify as candidate for improvement if a business case was established for an improvement. All processes within the company were possible candidates for improvements. They had improvement projects working on improving the following types of processes:
• Definition and improvement of an internal and external recruitment process, which
helped the company grown from 90 to 190 employees
• Improved testing of mainstream software products
• Improved ways of delivering customized software to clients
• Reduced the defect ratio with 60% in a software development process that used 70%
of the total R&D budget
• Established and improved a software defect handling process (Service pack process),
such that a major European Airline ranked it as best practice

Most topics that needed fixing were called “Ground fruits”, for which the root cause could
be identified by asking the question “Why” until they had drilled down to the root cause. For
example:

_They had an issue with their management of client experienced defects._

_Why is that so? Well, different employees mange the reported defects in different ways. Why
is that the case? A reported defect have different severity levels and the priority assigned to
the defect fix is depending on the importance of the customer, and to what extent the sales
manager working with the client can argue for the importance of a swift defect correction. In
summary the management of defects is ad hoc. Why is that the case? We don’t have an
agreed process for defect corrections._

The root cause in this case was that we simply didn’t have a defined process. Three simple
“why questions” managed to identify that fact. The Service pack process was defined,
documented and means to control the process was implemented. At a later stage they had
another issue with the Service pack process, and the issue at hand was that they had break of
Service Level Agreements (SLAs), as the defect corrections was delivered to late. The
resolution of this issue required that basic Six Sigma tools were employed. That is, the
following steps were taken in the Define phase:

• Project charter created (Business case, Problem & Goal statement, Scope,
Milestones, as well as roles & responsibilities). Company Quality Council (with
CEO as Chairman) decides if a candidate for improvement should be launched as an
improvement project. A project sponsor and a project manager would be selected,
key stakeholders identified, business case documented, project objectives
determined and project charter developed. The project charter was then approved or
disapproved by the Quality Council.
• CTQs (Critical To Quality) were determined
• A process map as-is was created, i.e., a SIPOC (supplier ⇒ input ⇒ process ⇒
output ⇒ customer) high lever process map of the current process.

6.2.6.2 Measure Phase

There was no silver bullet here! The measures taken would depend on the problem at hand,
and aimed at providing indicators of how well a process delivered according to the CQs.
Examples of measures (project Ys) were:

1. Number of defects reported from the field classified by severity level
2. Time spent on correcting defects
3. Lead time for defect correction, i.e., time from client reported defect until the fix
was available for the client to install.
4. Amount (SEK) of overdue invoices

The measures used were not connected to any “Big Y’s”.

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6.2.6.3 Analyze Phase

The company developed software, and the processes used within the companies were improved by means of various quality tools. More specifically, we wanted to identify the Root causes (Xs) of the problem at hand and we used the following tools:

- Ask why until root cause found
- Pareto diagrams
- Cause and effect diagrams (fishbone diagrams created based on brain storms)
- Process map analysis
- They excluded the statistical tools as they are more geared towards manufacturing industries with fairly stable processes and a large amount of data points.

Next step is to pin down the Xs that we judged as having the biggest impact on the project Ys. This was in most cases done by means of a Control/Impact matrix, i.e., a matrix what depicted level of control (In our control or out of our control, and degree of impact (High, Medium or Low). We did not use any statistical methods such as hypothesis testing, scatter diagrams or regression analysis. The final step in the Analysis phase is to quantify the opportunity. That is, the financial opportunity that was making up the business case in the project charter will be refined. Based on the data collected and analyzed earlier a new updated figure will be established for the financial opportunity of the process improvement. Note that no cost for implementing the improvement was computed at this stage.

6.2.6.4 Improve Phase

The deliverable from the improve phase is blueprints for the upcoming process improvement. These blueprints will be used to carry out a cost/benefit analysis. The DMAIC method employed by the company estimated the change cost in the Improve phase. However, given that the solution had been properly specified in the improvement phase a standard cost/benefit analysis was carried out to justify the implementation costs. In some cases the cost/benefit analysis was skipped as we just had to fix the problem with the budget provided by the Quality Council. The improvement will be done as a first step in the control phase. The exception to this would be if we decided to carry out a pilot to test all or parts of the proposed solution on a small scale. Such a pilot would be done during the improvement phase.

Implementing the proposed solution is the hard part. Many roadblocks may turn up and the planning of the implementation is crucial. The following issues are important:

- Having a Champion, who sponsors the change; who has visible, active public commitment and support of the change.
- Having a need for change that exceeds the resistance for change, i.e., the need for change (be it driven by threat of opportunity) is instilled within the organization and widely shared through data, demonstration, demand or diagnosis.
- Having a vision shaped in behavioral terms (do more of and do less of). The desired outcome of the change should, furthermore, be clear, legitimate, widely understood and shared.
- Having key stakeholders that agree to change their own actions and behavior to support the change.
- The improvement must be measurable, realized, and early wins must be established and communicated.
- Last but not least, management practices (staffing, rewards, communication, measures and organizational design) must be used to complement and reinforce the change.
6.2.6.5  Control Phase

The project Ys were still being measured after that the improvement was concluded. The sponsor of the improvement project was in most cases becoming the process owner and hence responsible for monitoring the project Ys and take action if the deviated from expected. The most important control mechanism put in place is the checklist used to audit if the processes is properly followed or not. Lessons learnt during the project should be stored as part of the company asset. The company stored lessons learnt reports in the same way for both improvement projects and regular development or delivery projects.

Six Sigma is best used in process or production industry, and many of the statistical tools have a direct and good use. The challenge is to employ Six Sigma software development. The main challenge is to identify the CTQs and to being able to establish cost efficient project Ys that can be used to indentify root cause, and measure improvements. Another challenge is that the processes used have quite long life span (a development project can take 2-3 years) and the processes are furthermore not to be classified as stable and repeatable.

6.3  Case Study Review A

6.3.1  Introduction

Let us move our attentions to Motorola. Motorola is the original inventor of Six Sigma approach. Six Sigma approach is declared by Bill Smith who is the Quality Engineer in Motorola in 1986. The original purpose is to improve the manufacturing process. Now it is applied to all business process. The detail is described in Chapter 2.2.

This case is referred from [6]. The purpose is to show how Six Sigma approach is used for software quality improvement. The details of project activities are presented below.

6.3.2  DMAIC Model

DMAIC model is selected as the main improvement model in this case. In following sections, main activities are summarized according to different phases [6].

6.3.2.1  Define Phase

Four activities are carried out in defined phase. The first one is to create a project charter. A project charter is very crucial for the project. A successful project charter help project to specify the right resources and boundaries. The necessary parts in this activity are to define project purpose, opportunity statement, project scope, project plan, project benefits and team selection. The project charter is used to get the commitment of all the team members and to facilitate the communication between them.

The second activity is to draw SIPOC which stands for Supplier, Input, Process, Output, and Customer. SIPOC uses a table to describe the suppliers of the resources, the inputs required by the process, the process description, the outputs from the process, and the customers. From SIPOC, we can easily identify the processes which need to be improved.

The Voice of customer is the following activity. During this activity, the needs and expectations of the customer are analyzed. Kano analysis is used for this purpose. The analysis result shows customer requirements and expectations which is also the main purpose of improvement.

The last activity in this phase is Quick Wins, in which the process under consideration is decomposed. The scope of the project is further narrowed according to a particular division.
Then tackle the first division. After that, the same process is repeated for other divisions. In this way lot of time is saved.

In this phase, not only project plan, scope and purpose are identified, but also we should analysis customer’s indeed requirements and expectations. That can validate our results in some extent. The chosen process (which is decided to be improved) is complex sometimes. Then we need to decompose it into smaller divisions. After all above, the project team can be formed. There is a very important condition, project goals and the chosen process must be clearly understood by each team member. Once the team is organized, the project can move to the next phase.

6.3.2.2 Measure Phase

The main activities in this phase are: identify what to measure, evaluate the measurement system, data collection, sources of variation, and sigma level calculation. In first activity, the current inputs, the process, and the outputs are documented. This activity helps to measure the problem in quantitative terms.

The second activity is to evaluate the measurement system. The measurement system is evaluated by looking at the following issues. The plan has to show works that have to be done, added or removed tasks which are handled as the project progress, and changes in project requirements.

The next activity is data collection in which the required data is collected. Once we have the data, we can display it graphically. The graphical display of data helps to find the sources of variation in the process.

The last activity of measure phase is the calculation of the sigma level. The detail of that is described in Chapter 2.2.3.1.

This phase’s main task is to measure the chosen process. Firstly we should make sure what needs to be measured. Then answer the question – is our measurement system good enough? If not, then it needs to be improved first. After that, the measurement is started. The aim of measurement is to identify the sources of variations. At last, the sigma level of chosen process is calculated. This level is used for the result comparison.

6.3.2.3 Analyze phase

Once the source of variations are measured, the analyze phase is started. The main activity in this phase is to investigate the sources. This is done with Pareto Analysis’s help. In Pareto Analysis, the relation of input and output variables is analyzed. That is to find out the areas that need to improve. The next activity is to find the co-relation between factors and defects, i.e. the correlation between release software size and defect injected. The last activity is to measure the quality from the customer point of view. This activity is very important for the test management, in order to plan the test time to reach the quality goals. It also helps to estimate when the goal is met.

The variations and their sources are identified. The following analyze phase focuses on discovering the relations which includes the relations between input and output, factors and defects, etc. This helps the project team to conduct the related solution.

6.3.2.4 Improve phase
In improve phase the first activity is to identify solution alternatives. For this activity either the team involved in planning is trained, or the mentors or people from project office are approached. Then each of the solution alternatives is evaluated with respect to the required criteria. They are statistically analyze, the identification for relationships between input and output variables. The effectiveness of the solutions and the cost will mainly influence the consideration. After evaluation, the most suitable solution is selected, and finally the selected solution is implemented.

Several solutions are conducted to solve the specific problem. The first work is to select the best one and its backups. The main selection criteria are solution effectiveness and cost. Because it is hard to balance them, so sometimes the best one which is chosen firstly may not fit the situation perfectly. That is why we need backup solutions.

6.3.2.5 Control phase

Control phase’s aim is to gain a long-term good performance. The first activity in this phase is the assignment of responsibilities. The solution is made part of normal practices. And responsibilities are given to team members for execution, evaluation and standardize the solution. This is believed to gain the phase aim [6]. The next activity is performance reviews. The performance reviews are very important to track the project and to evaluate the project success. Metrics are chosen for the review purpose, i.e. Fault Prediction Model, Defect Removal Model. The monthly performance reviews are done, which results in evaluating the long terms gains.

Good improvement result does not mean good long-term performance. Responsibility assignment and performance review protect the improvement result from two different ways.

6.3.3 Case Summary

This case reflects how Six Sigma approach works from software field. Compared with Company 1 project, there are some differences and similarities. The similarities are because they both choose DMAIC model as their main improvement tool. The differences happen for the reason that the fields are totally different (see Chapter 5.1 and 5.2).

6.4 Case Study Review B

6.4.1 Introduction

This case is referred from [6]. Customer Relationship Management (CRM) was started in 1990’s in United States. It is also known as Customer Service System or Call Center. It is a modern way of marketing. Computer telephone integrated technology and internet technology are used. Some world-class companies, like Microsoft and Oracle, have already adopted the CRM. By the use of the technology, companies gain more customer satisfaction and faster revenue growth [7]. The motivation behind the case study review in CRM is that it belongs to the service industry same as software’s. So later it would be helpful in proposing the steps for the implementation of Six Sigma in software’s.

The success rate of CRM can be improved by improving the CRM implementation processes. Figure 6.6 [7] indicates a Human Resource (HR) company using Six Sigma approach to improve its CRM implementation processes.
6.4.2 DMAIC Method

DMAIC method is main tool for Six Sigma process improvement project. In following sections, main activities are summarized according to different phases [7].

6.4.2.1 Define Phase

- Set project goals. The main goal in this case is to improve sale and service process. More specifically, to reduce 20% loss of opportunity and 50% reduction in customer complaints.
- Create As-Is process. It describes the process in a relative logical way, shown in Figure 6.7 [7].
• Define process metrics. Two process metrics were defined for service and sales quality in this case (see Table 6.1). The loss opportunity metric was to count the total number of opportunities that were lost. The customer complaint metric was to count the total number of complaints from customer.

<table>
<thead>
<tr>
<th>Process Metrics</th>
<th>Description</th>
<th>Data to Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of Opportunities</td>
<td>Measure how many opportunities are lost among all the opportunities.</td>
<td>Potential customer info, opportunity product, loss or not, competitors info.</td>
</tr>
<tr>
<td>Customer Complaints</td>
<td>Measure the number of the complaints received among all the possible complaints</td>
<td>Customer info, complaints problem, solved or not.</td>
</tr>
</tbody>
</table>

Table 6.1 Process metrics for sales and service quality [7].

• Organize a team for project. Team members are made up by IT specialists, project managers, CRM experts, and the CEO.
• Create project charter (see Figure 6.8 [7]).

From above, we can find that it is similar with the previous two cases. The project goals indicate when to terminate the project. As-Is process and process metrics help to analysis processes, furthermore to decide which process should be improved. At last, project team and project charter are conducted.

6.4.2.2 Measure phase

• Measurement. Measure the data for the loss of opportunity which includes following elements: name, address, telephone number, interesting services, opportunity loss or win, etc. And measure the data for customer complaints which contains customer information, complaint problem, and problem solved or not, and so on.
6.4.2.3 Analyze phase

- Identify the sources for problems. With the help of cause and effect diagram, the problems in the current process were analyzed (see Figure 6.9 [7]). Three main sources are identified in the current process. Firstly for the sales, no standard process was followed. Secondly in call centre information, no call information is saved. Thirdly salespersons cannot connect to ERP system.
- Refine the processes according to project goal.
- External solutions are considered. In this case, the project team decides to use MSCRM product for the call centre because of its standard sales process and friendly user interface.

![Figure 6.9 Cause and effect diagram for CRM implementation project [7].](image)

6.4.2.4 Improve phase

- Apply new system. In this case, a new MSCRM system is installed. Related training is conducted at the same time. There are three levels of trainings: administrator training, manager training, and end user training.
- Modify current process according to the result of analyze phase.

6.4.2.5 Control phase

- The performance of the new system was measure after three months. The Sigma level for the loss of opportunity was 1.25. And the Sigma level for customer complaints was 3.83. This shows the success of Six Sigma implementation for the CRM.
- New goals were identified for further improvements.

6.4.3 Case Summary

This CRM case is a little different with previous two cases. Company 1 and Case A are simply using Six Sigma approach to improve process. In this case, Six Sigma approach is
integrated with business method CRM. The final result shows that the DMIAC model can not only be used in single situation, but also works in complex integration projects. As Figure 6.6 shows, five DMAIC phases are divided into several steps. Each step has a clear defined input and output. The output of previous step mostly is the input of the next step. And finally, the project result is managed by control phase to keep a long-term performance.

From this case, we can find single CRM implementation process generates a low level success rate [7]. However with the help of Six Sigma approach, the results are significant improved. That means Six Sigma approach can not only improve process by itself, but also can integrate with other improvement method.

6.5 Case Study Review C

6.5.1 Introduction

In this case’s company, there is a Global Engineering Development Center (GEDC) which is located in India and China. The main purpose of GEDC is to execute projects of General Electronic (GE) Company. These projects are related to different areas, i.e. Computer Aided Design (CAD), Software Development for Engineering Automation, etc. GEDC has adopted Six Sigma in order to improve the quality of project processes. In 1998, the first Six Sigma project has been completed. Since then, many successful Six Sigma projects are generated and finally completed.

This case is chosen from one of these successful projects [6]. It was carried out at GEDC in 1998-1999. DMAIC model is chosen to apply with the quality compliance improvement.

6.5.2 DMAIC Method

DMAIC model is chosen to apply with the quality compliance improvement. The activities in different phases are described below.

6.5.2.1 Define phase

First of all, the problem in process is identified by calculating DPMO value. According to the current metric, DPMO value equals to $3.48\sigma$. So the project goal is improving the process capability to more than $4 \sigma$, and reduces the DPMO by 50%. Following activities are conducted:

- Identify the critical of quality factors.
- Create the Six Sigma project team. It owns members from different levels namely Project leaders, Team members, Module leaders and the Quality Team.
- For the current process the high level process mapping is made for problem identification, shown in Figure 6.10 [6].
- Define measurement system. Any attribute in the deliverable, which does not meet the customer requirement is considered as a defect.
6.5.2.2 Measure phase

The activities in the measure phase are described below:

- A measurement to the critical of quality factors is made. The field errors in the deliverables are classified as defects that have occurred in each process, as shown in Figure 6.11[6]. From the figure, execution process faces to a bigger defects value.

![Chart Title]

Figure 6.11 Measurement of defects for the key processes [6].

- Assess the poor input variables that effect the critical to quality factors (see Figure 6.12[6]).

![Projects affected by poor input quality]

Figure 6.12 Projects affected by poor input quality [6].

The first step is used to find which process needs to be improved, while the second step indicates poor input variables is the main reason which leads to poor performance. So the project team decides to analyze the effect of quality of inputs separately.

6.5.2.3 Analyze phase
The activities in analyze phase are described below:

- A cause and effect diagram is used to identify the key problem sources, as shown in Fig 6.13 [6].
- The main causes of deviation and the relationship between the variables is identified.
- The causes that lead to the non-conformance quality are listed.

Through above analyze steps, several key sources are located which is believed as the main reason that causes the problems.

6.5.2.4 Improve phase

The activities in the improve phase are described below:

- After analyzing the cause and effect diagram, a check list is introduced to prevent defects due to wrong inputs.
- A customer feedback form is introduced, having 1 to 5 scales. Using the form, the deliverables are rated by the customer.
- More solutions are indicated in Figure 6.14 [6] according to each process.
6.5.2.5 Control phase

The Sigma level is improved from 3.48σ to 3.98σ, which is very close to project goal. The lessons learnt in this whole process are applied in other Six Sigma projects.

6.5.3 Case Summary

This case gives us a new consideration – customer satisfaction. Six Sigma approach helps in creating and sustaining customer. Customer satisfaction is significantly improved by taking over the feedbacks from the customer. At the same time, the participation of team members from all levels in Six Sigma project has created a high effective and creative team work.

6.6 Summary

This chapter shows Six Sigma approach is an effective process improvement method from different fields. DMAIC model is chosen in all the cases which mean this model is competent in most situations.

Interview 1 has a manufacturing background. Because the production processes are repetitive and strictly structured, so generally the problem happens around the work flow and equipment. However, Six Sigma training courses are strictly executed. In Company 1, every employee is required to take that course. And some leader positions require the Black Belt certificate. Through the interview, we found the employee in company 1 has a very good understanding about Six Sigma approach. To a world-class company, this is very essential.

Interview 2 has a software background. Six Sigma training courses are provided for all employees. Through the interview, we understood the process of Six Sigma implementation.

Case A is based on a software project which is more valuable to our research. In this case, the project team puts more focuses on project scope, customer requirements, input and output variables, and the measurement for software system (software size, reliability, etc.). Compared with manufacturing case, the project flow is similar. Differences happen in the detail of each activity (what we measure, property of product, internal and external factors).

In Case B and Case C, we find Six Sigma approach can not only work in single process improvement project, but also can integrate with other improvement methods. Results from case study show that Six Sigma approach can help the implementation of CRM business model, CMM quality model, etc. Meanwhile, it can optimize and increase the success rate of those implementation process.

In each case, the Six Sigma project starts from defining the project goal and the problem which needs to be solved, then project team. The team members are selected from all levels inside or outside of company, for instance, CEO who comes from the top of company, Team Leaders who lead the project, customers involved from outside of company, and other members come from different departments within the company.

DMAIC model divides Six Sigma project into five phases. In each phase, there is a clearly define input and output. The output of the previous phase normally is the input of the next phase. In each phase, there are several steps to achieve phase goal. Numbers of quality tools are introduced to each step. There is only one criterion for quality tool selection – fitness for use. When the Six Sigma project is terminated, gained experiences will be documented and applied in other Six Sigma projects. Sometimes the project goal cannot be achieve by only
one Six Sigma project. Then more Six Sigma projects can be organized according to situation. The spirit of Six Sigma approach is towards a long-term improvement.
7 STEPS TOWARDS APPLYING SIX SIGMA IN SOFTWARE COMPANIES

This chapter presented a method by steps for applying Six Sigma in software companies. It is conducted by integrating all previous research findings.

The method which will be presented contains two main parts – environment establishment and an enhanced methodology. The first part is the foundation for conducting process improvement projects, while the other part is the main way to direct the project. Those two parts are presented separately as below.

7.1 Environment Establishment

Before we apply the methodology to development process, the Six Sigma environment shall be established first. From Chapter 4 and Interviews, we know a good Six Sigma environment not only support the implementation of Six Sigma project, but also continually cultivates Black Belts as the main force for Six Sigma team.

In [47], Magnusson and his partners have recommended twelve steps for introducing Six Sigma to manufacturing companies (see Figure 7.1). Magnusson uses many evidences and really cases to prove his method’s functionality. And we believe it really can help to establish Six Sigma environment. However, all cases and evidences point to manufacturing filed. And Magnusson also has said “Black Belts themselves may find it difficult to drive improvements in non-manufacturing process” [47]. About applying Six Sigma approach to other field of process, for example software company, we are very sorry to say there is no answer in Magnusson’s book.

However, Magnusson and his partners have shown us a way to solve the problem. If we integrate his method with software specific attributes, a specific method for software Six Sigma environment establishment is conducted.

7.1.1 Reform Superstructure

As we know, Six Sigma is a top-down approach. In software, generally there is a Project Management Office (PMO) which controls all company’s projects. So the superstructure of company shall be reformed first. Everyone within the PMO shall have a good understanding about Six Sigma approach, especially for CEO/CTO, Master Black Belt, human resource manager and financial manager.

CEO/CTO is the most importance person who supports the Six Sigma projects. Their work is resource allocation, task deployment, budget works, etc. In some sense, the success of implementation depends on how well the CEO/CTO knows the Six Sigma approach.
Master Black Belt (MBB) is the person who takes Champion position in Six Sigma projects. He/she is the coach who drives the whole process improvement project. In software companies, the special attributes require that MBB should have not only the excellent Six Sigma knowledge, but also the expert software project knowledge. CTO or Chief Software Architect (CSA) is the best options. Otherwise, a project manager with the Black Belt certificate can also be promoted as the Champion. A Champion’s work can be summarized as identifying improvement opportunities, developing action plan, leading to apply Six Sigma tools, communicating, and coaching.

Human resource manager and financial manager are also important roles within Six Sigma projects, which we have not mentioned before. Human resource manager need to help Black Belts selection, while financial manager is responsible for the cost reduction calculation.

As we mentioned in Chapter 4.1.1, Six Sigma is not only a methodology, but also a business strategy. If we want to have a successful Six Sigma project, top management’s support is very essential. That is why reforming the superstructure is needed.

To reform the superstructure, company can invite Six Sigma specialists as the consultant, or launch a specific Six Sigma course for top management. However, above options can only solve the problem temporary. The best way is to establish a Six Sigma education system which conducts a long-term effect.

**7.1.2 Establish Six Sigma Education System**

A grouped Six Sigma course is very necessary for companies from top to down. A well-designed education system can continuous cultivate talents for Six Sigma projects. Six Sigma approach will not conduct long-term improvement without education system’s support. That is why establishing an education system is so much essential.

Six Sigma course shall include both high-level which aims to Black Belts, and low-level which cultivate Green Belts (some companies may need a middle-level for Yellow Belts). Different levels share a same weightiness. A great number of full-time Black Belts are the guarantee for Six Sigma projects. They lead each single Six Sigma project, create project plan, communicate between project team members, and be responsible to report project status to top management. Generally, the selection of Black Belts is among project managers within the software company. Because in software, Black Belts shall not only need a great Six Sigma knowledge, but also own an expert software knowledge. Generally, candidates shall also have following attributes:

- Good education background – this is an education course. Good education background means learn fast.
- Young enough – young project managers can easily accept new concepts.
- Full-time work – Black Belts require the people put all his time and focuses on Six Sigma projects.

Green Belts are the main force for Six Sigma activities. They are the actual workers who carry out project plan. Without them, the Six Sigma projects are just papers. The candidates of Green Belts can be selected among common employees within the company.

Generally, the Black Belt courses are lead by MBB. And the selected Black Belts are responsible for Green Belt courses. In courses, a Six Sigma project must be run as a homework assignment for all participates. As the first project, successful cases will be recorded and shared within the whole company. By using this, the employees will be encouraged and motivated for learning Six Sigma.
7.1.3 Continuous Improvement

Why continuous improvement? That is because the quality will not be improved in just one single process improvement project. Continuous improvement focuses on a long-term performance. Numbers of improved processes and Six Sigma projects may lead a visible quality effect. It is not an easy job. On the other hand, if we do not keep continuous improvement, the performance of processes may turn back to the original or even worse. So, continuous improvement is necessary and important to company.

Continuous improvement is not just banners which catch people’s eyes. Indeed, it is made up by numbers of actual activities. For example, spread the successful improvement results to the similar processes, build up a common software development standard, provide some specific training to new group members, etc.

The Six Sigma environment will not improve quality and bring profits immediately. In contrast, it costs lots of resources and time. However, the environment is the foundation for all Six Sigma projects. Without that, the result of improvement will not last too long, and finally the improved process will back to before. To keep a long-term performance, environment establishment is very essential, and the cost will come back due to the improvement of quality.

7.2 An Enhanced Methodology

7.2.1 Methodology Selection

After the Six Sigma environment is established, we can start the real improvement projects. There are a number of methodologies can be used. Two main methodologies are recommended by Six Sigma approach – DMAIC model and DMADV model. The first one is used in existing process improvement. And the DMADV model is used in new process development.

Since all cases in Chapter 6 use DMAIC model, so in this section we decide to introduce this most popular model. The criteria for the proposed steps in the most used activities within each phase of the DMAIC model.

7.2.2 Enhancing DMAIC Model

DMAIC model is named by its five phases – Define, Measure, Analyze, Improve and Control (see Chapter 2.2.4). By analyzing previous cases in chapter 6, this methodology is enhanced by integrating with what have been learned from research. Authors describe those five phases separately in below sections.

7.2.2.1 Steps in Define Phase

In first phase, project members shall have a “big picture” of the process, which needs to be improved. To achieve that, process, problems, related customers and their requirements shall be identified first. After that, several properties shall be developed, such as project goal, scope, team, project plan, etc. From all cases which are introduced in Chapter 6, a comparison is conducted to identify differences and similarities (see Table 7.1).

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Activities</th>
<th>Tools</th>
</tr>
</thead>
</table>

In Company 1 case, activities are arranged in a reasonable sequence. Firstly, discover what should be improved. And that is also a part of project goal. SAP method is used to collect data which can help to identify the main problem. Then define project scope and develop project plan. According to each scope and plan, a proper team is organized. Then develop the final project charter which contains all information above. Company 1 define phase is simple and reasonable. However, it cannot be applied to software directly. Because in software, situation is more complex, there are lots of works need to do before we simply develop the project scope and plan.

In Company 2 case, the main activities for the define phase are Project charter, Critical to quality, and a process map. The tools used are SIPOC Diagram and As-Is process.

Compared with Company 1, Case A adds one more activity which is very important to software project. It is customer voice collection. In software, customer’s satisfaction is one of most important factors. It will be taken account to project goal in all software projects. At the same time, more tools are used to assist activities. For instance, SIPOC is used to help identify problem by describing resource suppliers, inputs and outputs, process, and customers. Kana analyze and VOC method is used to analyze customer’s requirements and expectations (more tools detail are introduced in Chapter 3).

The outstanding point of Case B is process breakdown activity. It uses As-Is Process and Process Metrics to break process which is very convenient to identify problem. At the same time, Case C uses quality critical factors for following project scope define and project plan develop.

By combining above cases’ successful activities with software property, following steps are conducted:
Identify problem. Every project starts from this step. It provides a improve direction for Six Sigma team. Several tools can help the progress of this step, e.g. Cause-effect Diagram, Pareto Chart, SIPOC Diagram, Process Mapping, etc.

Organize project team. Once problem is identified, proper team members shall be organized. This step is conducted before project plan, which is because all following steps need the full support form project team (Team organize information can be found in Chapter 6).

Identify key customers and elicit their requirements. This step comes from the customer voice collection activity in Case A. The key customers may come from external or internal of the company. External customers include the direct customers, system end-users, partners, etc. And the internal customers involve the finance department, development department, and sometimes market department. Generally the original customer requirements are rough, and some of them are valueless. Then we need Requirement Elicitation and Requirement Prioritization. Some tools can be used here effectively: SIPOC Diagram, Kano Analysis, VOC, etc.

Develop project charter. In a well defined project charter, following information shall be included: project goal, project scope, team information, project plan, project schedule (sometimes), etc. The sample of project charter can be found in Appendix E and Figure 6.8.

Activities in define phase own special meanings. All following phases and activities are generated based on this phase. A little mistake in this phase will lead to a big failure in future. So be very careful to each activity above.

7.2.2.2 Steps in Measure Phase

To discover the variations, the input data associated to the selected initial problem shall be measured, and then exports measure results to the following analysis phase. Below is the measure phase comparison for all cases in Chapter 6.

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Activities</th>
<th>Tools</th>
</tr>
</thead>
</table>
| Company 1 | Measure main problems and its causes.  
Prioritize causes and get the top six causes. | Process Mapping  
XY Matrix |
| Company 2 | Reported defects with severity level.  
Time spent on correcting defects.  
Lead time of defect correction.  
Amount of overdue invoices. | |
| Case A | Identify what to measure.  
Evaluate the measurement system  
Data collection.  
Identify sources of variation.  
Calculate Sigma level.  
Set software reliability goal. | SIPOC Diagram  
COQUALMO |
| Case B | Measure problem related data.  
Collect information.  
Check errors.  
Determine process baseline. | |
Case C

- Measure the critical of quality factors.
- Assess poor input variables.

Table 7.2 Activities comparison for measure phase between four cases.

From Table 7.2, Company 1, Case B and Case C do not conduct much more activities in measure phase, however Case A, and Company 2 does. The main reason is because this case is software based. Although it is outstanding compared with the other three cases, it still has some improper points. Measurement system evaluation should not be conducted in this phase. It shall be done before the Six Sigma project started. In above environment establishment section, we have made a clear description about measurement system. So in steps of this phase, this activity shall be removed. At the same time, source of variations shall be identified in the next analyze phase. Then following measure phase steps are generated:

- Determine what to measure. Using SIPOC Diagram to identify the related input data which needs to be measured.
- Conduct measurement according to measurement system. Process’s historical data and records will be very helpful to measurement. Several tools can be used, e.g. Histogram,
- Calculate Sigma level. The calculation method is introduced in Chapter 2.2.3.1.
- Amount of overdue invoices.
- Set software reliability goal. Although the project goal has been made, there is a necessary to refresh it by adding software reliability goal into consideration. The project goal generally is to solve the problem, and this reliability goal is more in detail. In Case A, it is a Sigma level which needs to be achieved.

This phase is very much depending on the measurement system which has been introduced in previous chapter. Sigma goal give us a clear visual number to achieve which will make the project more efficient.

7.2.2.3 Steps in Analyze Phase

By analyzing the measure results from the above phase, we can identify the sources of the variations and develop the methods to reduce them. Following table is the comparison of all cases’ activities in analyze phase.

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Activities</th>
<th>Tools</th>
</tr>
</thead>
</table>
| Company 1 | - Analyze problem sources.  
- Conduct solutions. | - 2-Proportion  
- Regression Analysis  
- Two-Sample Test  
- Kruskal-Wallis Test |
| Company 2 | - Ask why until root cause found.  
- Process map analysis. | - Cause and Effect Diagram  
- Pareto diagrams |
| Case A    | - Analyze sources of variations.  
- Identify the co-relations between software factors and defects. | - Pareto Analysis  
- GO Model |
| Case B    | - Identify problem sources.  
- Refine process. | - Cause and Effect Diagram |
Table 7.3 Activities comparison for analyze phase between four cases.

<table>
<thead>
<tr>
<th>Case</th>
<th>Activities</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Conduct solutions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identify key problem sources.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identify relationship</td>
<td></td>
</tr>
<tr>
<td></td>
<td>between variables.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>List defect causes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cause and Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FMEA</td>
<td></td>
</tr>
</tbody>
</table>

In Company 1, the project team uses plenty of quality tools for analysis. The aim is to find the main cause and conduct solutions. Several experiments are generated to reduce risks. In Case A, project team puts more focus on co-relations between software factors and defects, for example, the correlation between release software size and defect injected. This has a special meaning to software companies. Company 2, Case B and Case C use Cause and Effect Diagram (Fishbone Diagram) and Pareto analysis to help analysis.

Combining above opinions, following steps are conducted for analyze phase:

- Discover sources of variations. Process Mapping, Cause and Effect Diagram, and Pareto Analysis can be used as the analyze tool.
- Analyze problem causes. There may be many causes which lead to the problem. Each one owns a different weight. That is why some necessary analysis and prioritization are needed. Aim is to find the one or group which has the most influences. A sample of how to prioritize causes is shown in Figure 6.2.
- Brainstorming. After the main causes are selected, the Six Sigma project team shall organize a brainstorm meeting to generate ideas (the detail of brainstorming is described in Chapter 3.3.1.1). Any kind of ideas are allowed in the meeting. When the meeting is over, the ideas will be gathered and analyzed. Each idea will be scored according to team member and customer’s satisfaction. The top 5 (this number depends on the size of project) ideas will be the candidate solutions for the next step.
- Select the best solution. Tools and techniques need to be used to select the optimize solution among the ideas generated in above step. Experiment is highly recommended. The final solution shall satisfy both technical requirements and customer’s needs.
- Assess Risks. It will be good to assess risks before applying improvements. By using Failure Modes and Effects Analysis (FEMA), potential risks can be assessed and furthermore to be minimized.

Activities in analyze phase needs the help of plenty of tools. Some popular and effective tools are Cause and Effect Diagram, Process Mapping, FEMA, Pareto Analysis, etc. The best solution chosen in this phase is not always the best at last. Because all choices and decisions are based on tools, analysis, experiences, and predictions, so it is not always right. According to this reason, backup solutions are needed. Generally five more effective solutions will be selected as the backup.

### Steps in Improve Phase

When the project moves to this phase, the problem and its root causes are clearly identified and discovered. Additionally, the best solution and its backups are also ready. Now it is time to make the proposal come true.
By learning from four cases in Table 7.4, we can safely draw following steps:

- Gain Improvement Approval. The proposed improvement shall be approved by everyone involved in Six Sigma project, includes all project team members, Champion, top management, customer, related process operators. Make sure everyone can review it.
- Implement Solution. Once everything is ready, it is time to implement the approved solution. A well-designed formal project plan will lead the whole implementation. Make sure the defined delivers and milestones are reached on time, and keep contact between affected groups frequently.
- Gather customer feedbacks. If the project is customer involved, or the process is directly affect customers, customer feedbacks shall be collected timely and be used to modify project actions.
- Assess improvement results. It does not matter that this step shall be done in here or next phase. The improvement results will be compared with the statement before improvement. That will show how much improvement the project have done.

The first and third steps above are very important to software Six Sigma project. Firstly, the proposed improvement shall be reviewed and approved by all project members. It is not only about the team work, but also can reduce risks and failures. Customer feedback is one of the most effective methods to evaluate the improvement results. Their opinions directly decide the final result.

### 7.2.2.5 Steps in Control Phase

The project will never close without this phase. The last phase aims to long term performance. Without this phase, the process will turn back to its original status, and the improvement result will not last too long.
Case C
- Calculate Sigma level.
- Spread success to other Six Sigma projects.

Table 7.5 Activities comparison for control phase between four cases.

Through Table 7.5, two activities are conducted:

- Develop strategy for continuous improvement. Although the process has been improved and the problem has been solved, we do not know if the process will turn back to its original statement. Furthermore, the improvement of quality will never end. To keep a long term improvement and to avoid the solved problem happens again, setting down a strategy is necessary to keep continuous improvement. For instance, establishing standards to standardize employees’ behavior.
- Terminate project. Every project has a clearly defined start and end. If the project goal has not been reached, project leader will consider establishing another Six Sigma process improvement project. The failure will be summarized to avoid it happens in the next project. Too ambitious goal will be reformed. Whatever the result is success or failure, all the project activities, data and information will be well recorded to provide experience for other improvement projects. At the same time, a terminate project report shall be created (see Appendix F) and reported to top management.

7.3 Summary

In this chapter, authors have presented a method for Six Sigma implementation. Software companies and quality researchers can follow steps in this method to apply Six Sigma approach in their development processes.

This method was divided into two parts – environment establishment and an enhanced methodology. The Six Sigma environment is the basis for all Six Sigma improvement projects. It provides fully support and guarantee (financial, strategy, human resources, top management, etc.) to keep project towards success. As presented, this step contains three activities. The first one is to reform organization’s superstructure. In some place, it was called top management. The main purpose is to gain top management’s trust and commitment. If a Six Sigma project loses top’s focus, it won’t last to the end. Meanwhile, the principle of Six Sigma approach is continuous quality improvement. It needs continuous support from the superstructure. The second important activity is to establish Six Sigma education system. Long-term improvements need numbers of quality specialists. This system is built for this aim. Finally, company needs to establish some necessary standards or rules to keep continuous improvement.

DMAIC has been selected as the main model for organizing Six Sigma project. Research findings and software properties have been integrated with the selected model. Its functionality has been enhanced to meet software company requirements. Activities and quality tools were blended with each step in each model phase. By the purpose of practicability and authenticity, most of them came from interviews and case study reviews. Authors anchor their hopes on using this chapter to help software companies for quality improvement, and also supporting quality researcher’s further research.
8 **DISCUSSION AND VALIDITY THREATS**

This chapter contains a discussion section on the thesis work, and a section on validity threats.

8.1 **Discussion**

In this paper, authors have conducted a literature review for Six Sigma approach, a comparison between Six Sigma approach’s applicable fields, and an acceptance and motivation discussion for using Six Sigma in software, a real manufacturing interview, three successful case studies, finally a method for applying Six Sigma in software companies. The main outcome of author’s research is lessons learned from literature view, manufacturing interview and case studies. And those lessons are integrated with the final method. This method can be used as a guideline for software companies to implement Six Sigma for quality improvement purpose. And this method can also be used by researchers in area of quality for further research.

While investigated the concept of Six Sigma approach, authors found that Six Sigma approach had three forms for quality improvement. The first form is as a metric which equals to 3.4 defects per million opportunities. This is a requirement for the highest quality level. The final aim of Six Sigma is to reach this defect degree. The second form of Six Sigma approach is as a methodology. It basically provides two models for process improvement. DMAIC model is used for existed process improvement, while DMADV model can be used in new process development. The last form is as a management system, which is binding with company’s business strategy.

Several quality tools have been investigated and introduced after Six Sigma’s definition. Some of them have been successfully used for many years, while some were just invented. Using proper tools can accelerate our progress.

The field difference is the main hurdle for introducing Six Sigma approach to software. The investigation of manufacturing’s Six Sigma framework provided us a deep study in Six Sigma approach. And that also answered the question – what baffle Six Sigma’s implementation in software.

After the investigation of manufacturing framework, a comparison between manufacturing and software and an acceptance discussion for Six Sigma approach in software have been presented by authors. By using powerful and reasonable evidences against last century’s wrong assumptions, authors believe that applying Six Sigma approach in software is possible at this moment. At the same time, authors testified that there is a need for software to use Six Sigma approach for quality improvement.

To show the state-of-art of Six Sigma approach, authors have conducted one manufacturing interview and three case studies which came from software and other fields. In this interview and studies process, authors found an amazing coincidence. The usage of Six Sigma approach in those interview and cases are almost same, including the selection of methodology and Six Sigma activities. This finding gave us a big help on generating the general method for Six Sigma software implementation.

The final research result is mixed into a method for applying Six Sigma approach in software companies. And this is conducted by integrating all authors’ previous works. It can be used by software companies for implementing Six Sigma on their own development processes. It
also can be used by researchers for further research. Two main parts are involved –
environment establishment and the enhanced methodology. The first part provides software
companies and researcher a top-down introduction for Six Sigma framework. By learning
that, software companies and researchers can build their own framework. The other part is an
enhanced methodology. Authors have integrated lessons learned from the research with the
DMAIC model, which makes the model contain software characteristic. This method is
believed can handle all general cases.

At last but not at least, Six Sigma approach is a good tool for quality improvement. Through
the research, authors found it is possible to apply Six Sigma approach in software
companies. The final research result will help software companies and researchers step by
step to achieve their quality goals.

8.1.1 The Cost of Six Sigma

When we do investigation on the application of Six Sigma approach in reality, one
interesting thing catches our attentions. That is the cost of Six Sigma which including pre-
cost, project cost, maintenance fee, recruitment spending, etc. Meanwhile, all companies
which we have done interview or case study review are world-class ones in their specific
field, which are able to afford the cost during quality improvement. All these information tell
us the cost of Six Sigma is not cheap.

In Chapter 2 and 5, we have separately discussed that the cost spending on quality
improvement is not cheap but worthy. However, all evidences in our research have pointed
out that the cost of Six Sigma is not an easy burden for small size companies. To have a
long-term improvement or to keep a long-term high performance, the support from abundant
funds is very much essential.

On the other hand, currently the implementation of Six Sigma approach is on its initial
phase, especially for software. During the growth of understanding, self-improvement and
the integration between quality approaches, we believe the cost of Six Sigma can be reduced
on a reasonable and acceptable level.

8.2 Threats to Validity

Validation for threats is very necessary to validate research results. According to [9], four
main types of validity were conducted as below.

8.2.1 Internal Validity

The internal validity threats in the research are related to the procedures and experiences of
participants. In this paper, people involved in studies came from different levels. That will
influence the research result. Another threat relates to case studies, the chosen cases came
from different fields. Although this can help to generate the generic method for common
cases, it also can be a threat to puzzle researchers.

8.2.2 Construct Validity

To minimize this threat, the sources of author’s research materials general came from
trustable or certificated originations, such as IEEE, ACM digital library, etc. However, some
sources still have a low level risk. This may mislead authors’ research direction.

8.2.3 Conclusion Validity

The research conclusion concluded literature review, comparisons, interview and case
studies. There is a threat that authors have not exactly concluded the real research findings.
And to minimize this threat, authors have invited several friends to help validate research paper.

8.2.4 External Validity

External validity is related to generalize research results with whole population. To degrade this threat, literatures, cases were selected from different fields in authors’ research. At the same time, the research goal is to generate a generic method for software companies. So this part’s threat is minimized.
9 EPILOGUE

This chapter contains research conclusion, research questions revisited, and further works.

9.1 Research Conclusion

Six Sigma is successfully used in manufacturing industry for two decades. The challenge was to employ Six Sigma in software development. In this thesis research we have concluded that Six Sigma is applicable in software’s. There are differences between software and manufacturing process, but if we take care of them Six Sigma Works well in software’s. It can bring large benefits to software companies. There are software domains where Six Sigma is highly beneficial i.e. complex systems, mission critical systems etc. Six Sigma tools are very useful for software process improvement.

The main challenges of Six Sigma in software are to identify the CTQs (critical to quality) and to establish cost efficient project Ys that can be used to indentify root cause, and measure improvements. Another challenge is that the processes used have quite long life span (a development project can take 2-3 years) and the processes are furthermore not to be classified as stable and repeatable.

We have proposed steps for the implementation of Six Sigma in software. The steps are proposed after interviews and case study reviews. We believe that the steps are reliable. The final research result will help software companies and researchers step by step to achieve their quality goals.

9.2 Research Questions Revisited

In our thesis we have seven research questions. In this section, the research questions are revisited to see the outcome of our research paper.

9.2.1 What are the definitions of Six Sigma?

A detailed literature study is carried out to find out the definitions of Six Sigma. The literature study consist of articles, web materials books. The Six Sigma has definitions at three levels i.e. matrix, methodology and strategy. At matrix level Six Sigma is 3.4 defects per million opportunities which means 99.9997% defect free product. Six Sigma approach at methodology level is not just counting defects in a process or product, but it is used to improve processes. When we look at Six Sigma as a methodology, there are many models available for process improvement like DMADV, DMAIC etc. At strategy level, through experience, Motorola has found that using Six Sigma as a metric and as a methodology are not enough to drive the breakthrough improvements in an organization. Motorola ensures that Six Sigma metrics and methodology are adopted to improve opportunities which are directly linked to the business strategy. Now Six Sigma is also applied as a management system for executing the business strategy.

9.2.2 What is the condition of Six Sigma in manufacturing?

An interview 1 is conducted with company 1 in China to see the condition of Six Sigma in manufacturing. Also a real case study is conducted with company 1 to understand how Six Sigma is used to improve a process. We found that Six Sigma approach has been successfully applied in manufacturing for two decades. From the successful experiences, a successful Six Sigma project must base on at least four foundational activities. They ensure the progress of projects from top management to human resources. They are
- Top management
- Stakeholder involvement
- Training scheme
- Measurement system

When the foundation is well settled, a specific Six Sigma project can be started. From the successful cases, some models can be borrowed to help us to run the project. DMAIC model is a formalized improvement methodology which is the most popular one from successful cases. It contains five phases – define, measure, analyze, improve, control. Each phase has a clear defined aim and an outcome. It is not very hard to follow this sequence and achieve the project goal.

9.2.3 The applicability of Six Sigma in software’s and why software companies choose Six Sigma?

Six Sigma approach can be applied in software companies if we involve the right people, solving the right problem, and using the right method. At the same time, although using Six Sigma approach for process improvement costs a lot, it worth. Few defects, faster delivery and increased customer satisfaction will generate more potential profits than you think.

The differences between software and manufacturing are obvious and unavoidable. The main distinct factors of software are non-repetitiveness, unique input and output, cognition, visualization, and some external factors such as employee’s skill and knowledge. These differences are reflected on the software product and software process. Still applying Six Sigma approach in software companies is beneficial. Firstly, all deny opinions and misconceptions are built on the misunderstanding of Six Sigma approach and unfamiliar with the software. Secondly, we never say applying Six Sigma approach in software is just the copy of manufacturing’s method. The differences do exist. According to them, we need to modify the Six Sigma approach, as the same time with the software process. Change them to fit for software’s processes. And that demands further research and more experiments. It can help software companies to reduce defects, improve quality, increase customer’s satisfaction, and enhance market-share. That is also the answer of why software companies choose Six Sigma, especially for complex systems, mission critical systems, and legal responsibility.

9.2.4 What kind of tools and techniques are used in Six Sigma? Which of them are suitable for process improvement in software companies?

There is no a specific tool or technique for one specific phase in Six Sigma. Any tool that is helpful for the process improvement can be applied in Six Sigma project. However seven quality tools are most widely used in all kinds of quality improvement. They are Cause-effect Diagram, Pareto Chart, Flow Chart, Histogram, Check Sheet, Control Chart, and Scatter Plot. The other special tools are gathered from successful Six Sigma cases which include Brainstorming, Affinity Diagramming, SIPOC Diagram, MSA, VOC Method, Kano Analysis, and so on. Using the proper tool in the right place is the key factor which influences success.

9.2.5 What is the state-of-art for the implementation of Six Sigma in software?

Interview 2 is conducted to analyze the current state of Six Sigma in software’s. Furthermore different case studies are reviewed to find out the state-of-art for the implementation of Six
Sigma in software’s. In each case, the Six Sigma project starts from defining the project goal and the problem which needs to be solved, then project team. The team members are selected from all levels inside or outside of company, for instance, CEO who comes from the top of company, Team Leaders who lead the project, customers involved from outside of company, and other members come from different departments within the company.

DMAIC model divides Six Sigma project into five phases. In each phase, there is a clearly define input and output. The output of the previous phase normally is the input of the next phase. In each phase, there are several steps to achieve phase goal. Numbers of quality tools are introduced to each step. There is only one criterion for quality tool selection – fitness for use. When the Six Sigma project is terminated, gained experiences will be documented and applied in other Six Sigma projects. Sometimes the project goal cannot be achieve by only one Six Sigma project. Then more Six Sigma projects can be organized according to situation. The spirit of Six Sigma approach is towards a long-term improvement.

9.2.6 Steps towards applying Six Sigma in software companies for process improvement?

We have provided a method for the implementation of Six Sigma in software companies. The method was divided into two parts – environment establishment and an enhanced methodology.

The Six Sigma environment is the basis for all Six Sigma improvement projects. It provides fully support and guarantee (financial, strategy, human resources, top management, etc.) to keep project towards success. Environment establishment step contains three activities. The first one is to reform organization’s superstructure. In some place, it was called top management. The main purpose is to gain top management’s trust and commitment. If a Six Sigma project loses top’s focus, it won’t last to the end. Meanwhile, the principle of Six Sigma approach is continuous quality improvement. It needs continuous support from the superstructure. The second important activity is to establish Six Sigma education system. Long-term improvements need numbers of quality specialists. This system is built for this aim. Finally, company needs to establish some necessary standards or rules to keep continuous improvement.

DMAIC has been selected as the main model for organizing Six Sigma project. Research findings and software properties have been integrated with the selected model. Its functionality has been enhanced to meet software company requirements. Activities and quality tools were blended with each step in each model phase. By the purpose of practicability and authenticity, most of them came from interviews and case study reviews. Authors anchor their hopes on using this method to help software companies for quality improvement, and also supporting quality researcher’s further research.

9.2.7 What is the further work for Six Sigma in software?

We found a few areas during our research. These areas are related to Six Sigma and are very interesting for further research. Below is provided a list of topics.

- Comparing Six Sigma with other quality techniques.
- Blending Six Sigma with CMMI.
- Six Sigma for small sized companies.
- Lean Six Sigma.

9.3 Contributions
• Analysis of the applicability of Six Sigma in Software’s.
• The state-of-art for the implementation of Six Sigma in software.
• Steps towards applying Six Sigma in software companies for process improvement.

9.4 Six Sigma and Agile Software Development

Agile software development and Six Sigma both focuses on satisfying the customer requirements. There end goal is same. Both focus on reducing the failure rates and improving the customer satisfaction. The way an agile software development project runs, it closely parallels the way Six Sigma DMAIC approaches the project [77-79].

9.4.1 Agile principles align with Six Sigma

The Table 9.1 [79] below shows the Agile principles align with Six Sigma.

<table>
<thead>
<tr>
<th>Agile Principles</th>
<th>Six Sigma Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The main focus is to satisfy customer through timely quality software.</td>
<td>Six Sigma provides strong tools to gather requirements and measure customer values.</td>
</tr>
<tr>
<td>Business people and developers both are involved throughout the project development.</td>
<td>Six Sigma provides clear or more visible requirements and design so that they can be discussed between business and development people.</td>
</tr>
<tr>
<td>Attention to technical issues and good design throughout the development.</td>
<td>Six Sigma compares different design choices based on technical issues which drive continuous attention.</td>
</tr>
<tr>
<td>Provides simplicity means maximizing the kind of work that should not be done.</td>
<td>Six Sigma clarify that what is important and what is not.</td>
</tr>
<tr>
<td>Agile processes provide sustainable development.</td>
<td>Six Sigma helps in sustainable and long term pace development.</td>
</tr>
<tr>
<td>The most suitable method for information sharing is face-to-face conversation.</td>
<td>Six Sigma also subscribes to this.</td>
</tr>
<tr>
<td>Frequent delivery of working software i.e. weeks, months.</td>
<td>Six Sigma also stay away from the bigger deliveries.</td>
</tr>
</tbody>
</table>

Table 9.1 Agile principles align with Six Sigma [79].

9.4.2 Requirements understanding

The most common reason behind the failure of a software project is misunderstanding the user requirements. Agile methods use an iterative approach for requirements understanding. In Agile software development the customer is very much involved which make it easier to understand the requirements. In Six Sigma one of the primary objectives is to align business goals with the customer requirements. The DMAIC phases focus on customers’ expectations and its tools helps to achieve this goal [78].

After the above discussion we can conclude that Six Sigma tools together with Agile development can help in understanding the real needs of the customer. In next section, the use of some Six Sigma tools with Agile projects is presented.
9.4.3 Agile software project and Six Sigma tools

In an Agile software development project Six Sigma tools can bring large benefits i.e. improved quality. Following are some Six Sigma tools and their application with Agile software development projects. The examples are from the two popular methodologies Scrum and Extreme Programming [78].

- **Using Voice of the Customer:** In Six Sigma voice of the customer (VOC) is used to understand the customer’s needs. Using this technique the customer is identified and the data is collected. In Agile software development project the customer is present in the team meetings. However, in huge projects with large organizations there are many direct and indirect customers. It is unfeasible to have everyone and discuss all the issues in the sprint review meeting (in the Scrum methodology). Using VOC before coming to the sprint review meeting will make the meeting more useful.

- **Building a Critical-to-quality Tree:** In Six Sigma a critical-to-quality (CTQ) tree is used to convert the customer requirements into specific features in the final product. It will be useful to draw the CTQ tree in the sprint review meeting.

- **Failure Mode and Effects Analysis for Design:** Failure mode and effects analysis (FMEA) design is used to keep track of the design failures with the project progress. Agile projects are iterative projects. To the iteration, design decision based on requirements can be a risk for the next iteration due to new requirements. Here FMEA can be useful. By maintaining a FEMA for iterations, the development team can analyze the failure points ahead of time.

9.5 Further Works in Six Sigma

During the thesis, authors found some interesting topics related to Six Sigma. These topics are important for further investigation. These topics have not been discussed in this thesis due to time constraints. A list of these topics is provided below.

9.5.1 Comparing Six Sigma with other Quality Techniques

There are many quality improvement techniques i.e. CMMI, ISO 9000. It is good area to have a comparison between Six Sigma and other quality improvement techniques. These comparisons can be made on the base of different factors. They would be helpful to understand Six Sigma with respect to other techniques.

9.5.2 Blending Six Sigma with CMMI

CMMI (Capability Maturity Model Integration) is also a quality improvement technique. It would be very interesting to find that can CMMI and Six Sigma be used together. How companies can blend CMMI and Six Sigma? Is there any possibility for a company using CMMI to implement Six Sigma as well? And at which level of CMMI the company should use Six Sigma for further improvements?

9.5.3 Six Sigma for Small Sized Companies

Six Sigma approach can be well adopted by large and medium sized companies. These companies have good resources, time and budget. But it would be interesting to find the applicability of Six Sigma in small sized companies.
9.5.4 Lean Six Sigma

Lean Six Sigma is an improvement methodology. It combines lean manufacturing and Six Sigma. The focus of Lean is on speed and the focus of Six Sigma is on quality. It would be very interesting to have discussion on the combination of Lean and Six Sigma.
REFERENCES


## Appendix A. DPMO Value to Sigma Level Conversion Table

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### APPENDIX B. CONTENT OF FIVE TRAINING COURSES

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<th>Subjects</th>
<th>White Belt course</th>
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<th>Management course</th>
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<td>Benchmarking</td>
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<td>Cost of poor quality</td>
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<td>Design of Experiments, Taguchi Design</td>
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<tr>
<td>Regression and correlation analysis</td>
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<td>Robust design and tolerance design</td>
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<td>Statistics, tolerance design</td>
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APPENDIX C. INTERVIEW QUESTIONS WITH COMPANY 1

Organization Field:

1. Does every factory in the company have its own Six Sigma department? Or several factories share one Six Sigma department?

2. What is the structure of Six Sigma department? How many people work in it? How many black belts and green belts?

3. Is there any Six Sigma training? How is it? Is it only for Six Sigma department or for all departments? Which people are selected for training?

4. How is the co-ordination between Six Sigma department and other departments?

Six Sigma Daily Works:

5. How do you identify the problems which need to be improved? (Define phase)

6. Who will be involved when deal with a specific problem? How to distribute roles and responsibilities?

7. How do you measure the problem conditions? (Measure phase)

8. How do you analyze and plan to solve the problem? (Analysis phase)

9. Which tools are frequently used? Which Six Sigma tool you are using? Why choose them?

10. How do you estimate change cost? Which factors will influence the decision? (Analysis phase)

11. How do you implement the plan? Is there critical issues? (Improve phase)

12. How do you monitor and record the implementation? (Control phase)

13. How to analyze the results? On which elements you pay more attention?

14. How to mange and store Six Sigma data?

15. After solving the problem, how you measure improvements?

16. Can you describe a regular example for us? From the problem identification to result analysis.

17. Have you gain any good or bad experience among the Six Sigma daily works? What are them? And why?

18. Does the company apply Six Sigma in other domain? E.g. In software?

19. Are there any other activities you perform? And the reasons?
APPENDIX D. INTERVIEW QUESTIONS WITH COMPANY 2

Interviewee Introduction

1. What is your name?
2. What is the name of organization u were working while implementing Six Sigma?
3. What was your position in the organization where you implemented Six Sigma?
4. What is your educational background?
5. Does u have any certification in Six Sigma?
6. What kind of experience does u have?

The interview questions are related to Six Sigma and the focus in each question is specific for Software Companies.

Organization structure:

7. Do the software companies have a special department for Six Sigma?
8. What is the structure of Six Sigma department? How many people work in it? How many black belts and green belts?
9. Is there any Six Sigma training? How is it? Is it only for Six Sigma department or for all departments? Which people are selected for training?
10. How is the co-ordination between Six Sigma department and other departments?

Six Sigma Daily Works DMAIC Phases:

11. Tell me how you identify the problems specific to software which need to be improved? (Define phase)
12. Who will be involved when deal with a specific problem? How to distribute roles and responsibilities?
13. Tell me how you measure the problem conditions? (Measure phase)
14. Tell me how you analyze and plan to solve the problem specific to software? (Analysis phase)
15. Which tools are frequently used specific for software’s? Which Six Sigma tool you are using? Why choose them?
16. Tell me how you estimate change cost? Which factors will influence the decision? (Analysis phase)
17. Tell me how you implement the plan? Is there critical issues? (Improve phase)
18. Tell me how you monitor and record the implementation? (Control phase)
19. Tell me how to analyze the results? On which elements you pay more attention specific to software?

20. Tell me how to manage and store Six Sigma software data?

21. After solving the problem, how you measure improvements?

22. Can you tell me about the hurdles when implementing Six Sigma in software companies?
### APPENDIX E. PROJECT CHARTER FROM SIX SIGMA PROJECT IN COMPANY 1

<table>
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<tr>
<th>Champion - CTQ</th>
<th>Product improvement company competence improvement.</th>
<th>Customer</th>
<th>SEM xxx department and xxx company</th>
<th>Champion</th>
<th>xxx</th>
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<tbody>
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<td>Big-Y</td>
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<td>Defects decrease</td>
<td>Department Manager</td>
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<td>P/J Name</td>
<td>72E&amp;96CV CUTTING improvement</td>
<td>Problem Description</td>
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<td>CUTTING project</td>
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<td>Department Die</td>
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<td>Appearance checking project</td>
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<td>Aim</td>
<td>72E&amp;96CV CUTTING improvement (defects number reduces from 54420PPM to 10000PPM)</td>
<td>TEAM members</td>
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<td>Goal</td>
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<td>Defects Number (PPM)</td>
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<td>M '07. 12.12</td>
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<td>10000 PPM</td>
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<td>A '07. 12.26</td>
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<td>C '08. 01.26</td>
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<td>F '08. 02.05</td>
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<td>Profit</td>
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<td>End '08. 02.05</td>
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- *Profit: \[
  \text{month output*defects reduce rate*unit price*12 months} = \frac{7762000*0.0444*0.02*1}{2} = 82838.036
  \]
# APPENDIX F. PROJECT TERMINATE REPORT FOR SIX SIGMA PROJECT IN COMPANY 1

## Project Terminate Report

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### Schedule

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<td>End Date</td>
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### Summary for main activity

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<td>The defects of 72E&amp;96CV is 2456PPM</td>
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### Results for main activity

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<th>Goal</th>
<th>After Improvement</th>
<th>Decrease Rate</th>
<th>Remark</th>
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<th>Decrease Rate</th>
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<table>
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<th>Month Capacity<em>Defects Decrease Rate</em>Price*12 Month</th>
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<td>=73K(USD)</td>
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### R&D GROUP

- Increase Profit
- Defects of 72E&96CV
- σ Level
- Planned End Date
- End Date
- Before Improvement
- After Improvement
- Decrease Rate
-Remark
- Department Manager
- Affair Office
- Finance Manager
- Champion

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