DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SIX SIGMA AND AN APPLICATION IN CONSTRUCTION SECTOR

by
Onur SERİN

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İZMİR

SIX SIGMA AND AN APPLICATION IN CONSTRUCTION SECTOR

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We have read the thesis entitled "**SIX SIGMA AND AN APPLICATION IN CONSTRUCTION SECTOR**" completed by **ONUR SERİN** under supervision of **ASST. PROF. DR. ÖZCAN KILINÇCI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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SIX SIGMA AND AN APPLICATION IN CONSTRUCTION SECTOR

ABSTRACT

Six Sigma is known as one of the quality control principles and a lot of studies have been done about Six Sigma until today. These studies were related to improvement of processes, customer satisfaction, reducing cost, production time etc. In this thesis, implementation of DMAIC (Define-Measure-Analyze-Improve-Control), known as Six Sigma methodology is studied in a construction sector company.

Firstly, the problem is defined according to DMAIC methodology. Then, the necessary measurements are done and analyzed by using statistical techniques. After that, necessary improvements are determined by factorial experiment method and results of executed improvement are controlled.

Key Words: Six Sigma, DMAIC, Factorial Experiment Design, Six Sigma in Construction Sector

ALTI SİGMA VE İNŞAAT SEKTÖRÜNDE BİR UYGULAMA

ÖZ

Kalite kontrol yöntemlerinden birisi olan Altı Sigma ile ilgili bugüne kadar birçok çalışma yapılmıştır. Bu çalışmalar değişik sektörlerde; süreçlerin iyileştirilmesi, müşteri memnuniyetinin arttırılması, maliyetin azaltılması, üretim zamanında iyileştirmeler gibi birçok konuyu içermektedir. Bu tezde, Altı Sigma'nın yöntemlerinden TÖAİK'in (Tanım-Ölçme-Analiz-İyileştirme-Kontrol) inşaat sektöründe yer alan bir firmada uygulanabilirliği araştırılmıştır.

İlk olarak, yönteme uygun olarak problem tanımlanmış, daha sonra gerekli ölçümler yapılmış, bu ölçümler istatistiksel yöntemlerle analiz edilerek gereken iyileştirmeler faktöriyel deney tasarım yöntemi ile belirlenerek uygulanmış ve bu iyileştirme sonuçlarının neler olduğu gözlemlenmiştir.

Anahtar Sözcükler: Altı Sigma, TÖAİK, Faktöriyel Deney Tasarım, İnşaat Sektörü Altı Sigma

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

Some of the most important principles in the globalized economy are customer satisfaction and to produce products with the cheapest cost in the shortest time. One of the ways for reducing the cost of produce and increasing customer satisfaction is to implement the proper quality tools at the right time.

Six Sigma is a quality application that, guiding to companies for producing products with cheapest cost in the shortest time and also guiding to increase customer satisfaction.

Many improvements and benefits about processes, productions and customer satisfaction have been provided by different firms, since Six Sigma was started to implement by Motorola in 1980s.

This study is one of the researches that are about the benefits of Six Sigma and the applicability of Six Sigma in construction sector. The aim is to give brief information about Six Sigma, and to examine the applicability of Six Sigma in processes of construction sector.

This study consists of five chapters:

First chapter is about the main information and the aim of the thesis.

Six Sigma will be explained in the second chapter. For this purpose, definition of Six Sigma will be done and historical information of Six Sigma, benefits of Six Sigma and the main objects of Six Sigma will be informed. Nonetheless, this chapter will include previous extensive researches in production, service and construction sector.

In the third chapter, there will be detailed information about DMAIC methodology. To this end, DMAIC's steps; Define, Measure, Analyze, Improve and

Control will be particularly provided. Separately, there will be large information related with most widely used statistical techniques for DMAIC methodology.

The fourth chapter will include studies about the applicability of Six Sigma in construction sector. First, the aim of application, then company and project will be explained. After then, application of DMAIC methodology will be defined. In “Define Phase”, problem will be identified; information about the preparation to application will be given. In “Measure Phase”, measurements and measurement results will be furnished. In “Analyze Phase” measurement results which will be obtained by using statistical techniques will be analyzed. “Improve Phase” will include necessary improvements and applications which will be determined by using statistical techniques. Finally, in “Control Phase”, results of improvements will be checked and received data will be issued.

Last chapter will deal with results and effective yield of thesis. Conclusions and further recommendations for further surveys will be also given in this chapter.

CHAPTER TWO
SIX SIGMA

2.1 Definition

Since standard deviation is formulated by Galton in 1866, Greek Letter Sigma (σ) is used for symbol of standard deviation in statistics and probability.

If standard deviation is the measure of variation and dispersion of a set value with basic definition, Six Sigma is the spread about mean with % 99, 74 of a set value in normal distribution.

When Six Sigma is thought with real life situations, "Sigma value of 6, as used by many Six Sigma practitioners, represents a so-called world-class performance standard of 3.4 defects per million opportunities" (Truscott, 2003, pg 3) and Six Sigma is an approach that improvement of quality by preventing failures and improving processes but in fact, it is the way of customer satisfaction in business strategies.

Different ways and words are used to define Six Sigma by many scientists but in fact, same meaning is defined in their own words:

According to Goh (2002), Six Sigma as a systematic framework for quality improvement and business excellence has been popularized for more than a decade.

According to Kwak & Anbari (2006), the Six Sigma method is a project-driven management approach to improve the organization's products, services, and processes by continually reducing defects in the organization. It is a business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance.

According to Antony (2008), Six Sigma is a highly disciplined, customer-oriented and bottom-line driven business improvement strategy that relies on statistical methods to make dramatic educations in defect rates in processes; manufacturing, service or transactional. Organizations that implement Six Sigma have benefited from it in three major ways: reduced defect rate; reduced operational costs; and increased value for both customers and shareholders.

According to Thomas, Barton & Okafor (2009), Six Sigma can be considered both a business strategy and a science that has the aim of reducing manufacturing and service costs, and creating significant improvements in customer satisfaction and bottom-line savings through combining statistical and business process methodologies into an integrated model of process, product and service improvement.

2.2 Purpose of Six Sigma

To grasp the role of Six Sigma is very important for explaining the basic purpose of Six Sigma.

Six Sigma provides a production with only 3.4 incorrect units over a million products.

Figure 2.1 indicates the amount of defective products over a million in production, corresponding to sigma levels.

The core purpose of Six Sigma is to improve the performance of processes. By improving processes, it attempts to achieve three things: the first is to reduce costs, the second is to improve customer satisfaction, and the third is to increase revenue, thereby, increasing profits (Park, 2003, pg. 4).

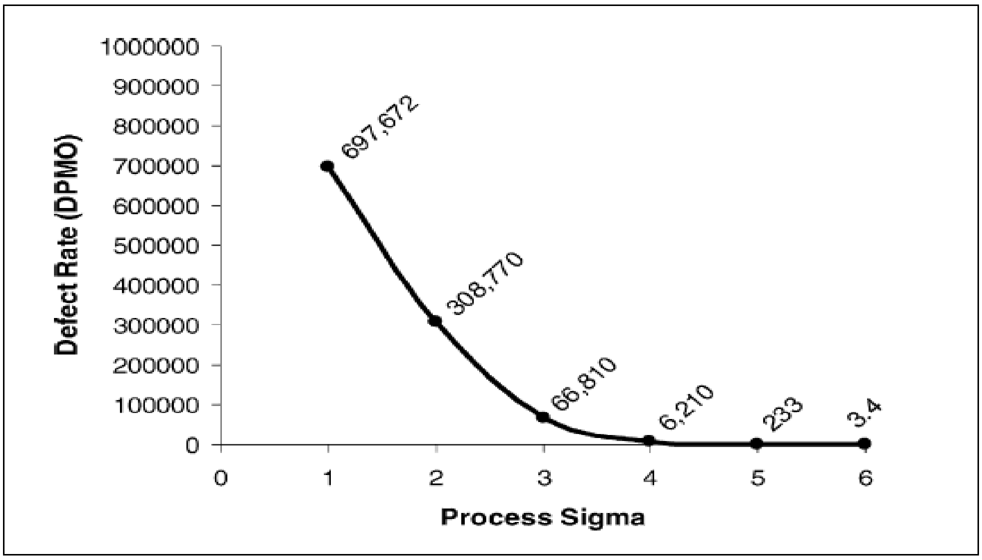


Figure 2.1 Defect rate versus sigma level (Linderman, Schroeder, Zaheer, & Choo, 2003).

2.3 History of Six Sigma

The roots of Six Sigma as a measurement standard can be traced back to Carl Frederick Gauss (1777-1855) who introduced the concept of the normal curve. Six Sigma as a measurement standard in product variation can be traced back to the 1920's when Walter Shewhart showed that three sigma from the mean is the point where a process requires correction (The History, n.d.).

Motorola engineering scientist Bill Smith, known as the father of Six Sigma, developed the concept in the 1980s. For many years, he and other pioneering engineers and scientists worked on this or similar concepts to reduce variation, improve quality, and maximize productivity, including Walter A. Shewhart, W. Edwards Deming, Philip R. Crosby, Shiego Shingo, Taiichi Ohno, and Joseph Juran. Each one studied quality from a different angle (Taghizadegan, 2006, pg. 4).

Six Sigma provided Motorola the key to addressing quality concerns throughout the organization, from manufacturing to support functions. The application of Six Sigma also contributed to Motorola winning the Malcolm Baldrige National Quality award in 1988 (About Motorola, n.d.).

Since then, the impact of the Six Sigma process on improving business performance has been dramatic and well documented by other leading global organizations, such as General Electric, Allied Signal, and Citibank. That's why investing in Six Sigma programs is increasingly considered a mission-critical best practice, even among mid-sized and smaller firms (About Motorola, n.d.).

Today, a lot of companies use Six Sigma to improve business performance of own companies.

2.4 Principles of Six Sigma

Six Sigma is a systematic, data-driven approach using the define, measure, analyze, improve, and control (DMAIC) process (Kwak, & Anbari, 2006) and makes the bellow principles:

2.4.1 Increasing Customer Satisfaction

Customers are the first priority of Six Sigma. Therefore, Six Sigma starts with performance review of customer satisfaction. Success of Six Sigma is defined by the impact on the customer satisfaction and assessments.

Customer satisfaction is defined as a customer’s overall evaluation of the performance of an offering to date (Gustafsson, Johnson, & Roos, 2005). Empirical results point toward a significant relationship between customer satisfaction and economic performance in general, but less is known about how the satisfaction of companies’ customers translates into securities pricing and investment returns, and virtually nothing is known about the associated risks (Fornell, Mithas, Morgenson III, & Krishnan, 2006).

Today, necessary steps to provide and improve the customer satisfaction may sorted as follows: (Madenli, 2006, pg 46)

- Identification of products and services which is provided by each person or department.
- Identification of customers for each products or services
- Identification of requires to correspond the customer’s needs.
- Identification of processes.
- Frame of processes.
- Providing of continuous improvement by measuring, analyzing and controlling of improved processes.

On the road of achievement, to increase the customer satisfaction is one of the principles of Six Sigma; due to Six Sigma is a guide for achievement.

2.4.2 Data-Based Management

In recent years, despite the importance of data, the measuring process, information management, information technology, etc., most of the business decisions are still based on ideas and assumptions. The data-based approach to decision making is consistent with the goals of applied behavior analysis (Pfadt, & Wheeler, 1995).

First step of Six Sigma applications is to determine necessary metrics for estimating key business performance. Later, these criteria are used to understand the critical variables and to optimize the results.

Six Sigma helps managers to answer two fundamental questions for supporting the based on data, decisions and solutions: (Madenli, 2006, pg. 38)

- What data / information really needed?
- The data / information, how can I use it to maximum benefit?

2.4.3 Process-Oriented

Six Sigma is a management innovation methodology to produce virtually all products that are defect free based on the process data. The activities for Six Sigma are not limited to process or operation levels, but extended to all the levels of an enterprise to reduce cost and produce high quality products (Han, & Lee, 2002).

To carry out a successful process:

- Objectives must be clearly identified.
- It should be clearly understand what the problem is.
- The key processes of the organizations must be clearly defined, classified and mapped.
- Improvement in skills should be developed in the organization.
- Improvements should be able to continue itself in the organization.
- Calculability must be in the organization.

2.4.4 Limitless Cooperation

This expression is one of the words of John Welch who is a Six Sigma guru about limitless business success. The Cooperation of companies other brings great opportunities with their suppliers and customers or employees.

The high amount of time, waste of money and effort occur due to communication gap or the competition between groups who must work together for adding of value to customers.

Six Sigma provides to determine real needs and processes for adding of value to the customers. And it helps to understand where the employee in this formation.

2.4.5 Target to Perfect and Tolerate to Failure

It is not easy to provide excellence without taking risks. If the employees are afraid to take risks or they are afraid from the results of own efforts, then the required perfection cannot be provided. Therefore, the mentality of “not to be afraid from the results of own efforts” should be taught to employees and requirements must be provided for quality.

Six Sigma has the risk management and therefore, targets may lead to failure like success. But the risk management must be always in business strategy for excellence.

2.5 Benefits of Six Sigma

Six Sigma is an important approach which is used to improve level of quality at organizations in recent years. Benefits, improvement and protection of competiveness are obtained by the companies by application of Six Sigma in their organizations.

The aim of approach should be mattered when the benefits of Six Sigma is mentioned. When Six Sigma projects are used correct and effective, it obtains gain and benefit of high percentages to the organizations. The benefits of Six Sigma may be summarized as such: (Madenli, 2006, pg 12)

- It decreases the costs.
- It increases the efficiency.
- It grows the market share.
- It changes the culture of organizations.
- It develops consumer loyalty.
- It decreases the failures.
- It increases the product and services.

As a result of Six Sigma projects which are applied by company: (Madenli, 2006, pg 12)

- Sustainable achievement is obtained.
- Common purpose of performance is formed for all of employee.
- Speed of development is increased.
- Strategic revolution is facilitated.
- The value of customer is increased.

Six Sigma has since been successfully applied in manufacturing organizations such as General Electric, Boeing, DuPont, Toshiba, Seagate, Allied Signal, Kodak, Honeywell, Texas Instruments, Sony, etc. The reported benefits and savings are composed and presented from investigating various literatures in Six Sigma (Kwak, &Anbari 2006). The Table 2.1 summarized the different benefits of Six Sigma at some companies after implemented.

Table 2.1 Reported benefits of Six Sigma (Kwak, & Anbari, 2006)

Company/Project	Metric/Measures	Benefits/Savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot Maintenance inspection time	Reduced %88 as measured in days
GE/Railcar Leasing Business	Turnaround time at repair shops	62% reduction
Allied Signal (Honeywell)/laminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Up %50 Down %50 Down %50 Increased to near %100
Allied Signal (Honeywell)/pendix IQ brake pads	Concept to shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft's missiles systems group/wave soldering operations	Quality/production	Improved 1000% Improved 500%
General Electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years
Dow Chemical/rail delivery project	Financial	Savings $ 2.45 million in capital expenditures
DuPont/Yerkes plant in New York (2000)	Financial	Saving of more than $25 million
Telefonica de espana(2001)	Financial	Saving and increases in revenue 30 million euro in the first 10 months
Texas instruments	Financial	$600 million
Johnson & Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

The benefits of Six Sigma were surveyed and mentioned at many papers by journalist:

Linderman & other. (2003), indicated that in 1999, General Electric Company spent over half a billion in Six Sigma initiatives and received over two billion in benefits for the fiscal year.

Mortimer (2006), reported the benefits of Six Sigma after implemented at a UK company that The Six Sigma has enabled the company to develop a far better understanding of some of its key processes, and as a result these are now being operated more consistently, with more confidence. Moreover, the initial projects completed by both black and senior green belts have significantly reduced the disruption to downstream processes, caused by the low yields, and this has had a major positive impact on production throughput. They have also generated direct annual cost savings of around £250,000 per annum.

According to Pandey (2007), Dow Chemical's HR resource center saved $3.2 million in financial benefits through Six Sigma implementation .Ford reports more than $1 billion saved since 2000, as a result of Six Sigma initiatives. HR practitioners at Ford Europe and Intel have significantly improved their internal processes based on such initiatives.

2.6 Literature Review About Six Sigma

Six Sigma approach is implemented by lots of companies from different sectors. Six Sigma approach has been examined and explored by many researchers and scientists.

At this section, researches about Six Sigma approaches in manufacturing, service and construction sectors are examined and described:

2.6.1 Researches in Manufacturing

Most of the quality approaches have been presented in manufacturing sector. Six Sigma was also developed in manufacturing sector like other quality approaches, and a lot of researches had been done related to Six Sigma in manufacturing sector.

Holtz, & Campbell (2003), examined a Six Sigma application about maintenance functions of Ford. DMAIC Methodology applied as follows:

In Define Phase, one recent project focused on minimizing unscheduled maintenance (UM) labor on environmental chambers. Although environmental chambers ranked fifth in total maintenance hours, they had a high proportion of UM hours, making them a prime candidate for improvement. For this project the Critical-to-Quality (CTQ) included: minimized equipment downtime, flexibility in PM(Preventative Maintenance) scheduling, maximized operational effectiveness of the equipment. They used various Six Sigma tools and principles, to ensure their understanding of the problem, including: a fishbone diagram to brainstorm potential failures, a SIPOC (suppliers, inputs, process, outputs, customers) diagram to identify contributing inputs and affected outputs; a high-level process map for understanding the overall process and context in which this maintenance was conducted; and a cause and effect matrix to quantify the impact of inputs to customer CTQs.

In Measure Phase, the team obtained a dataset of all work orders for environmental chambers including a brief description of work requested and characteristics. A common metric used in Six Sigma is DPMO (defects per million opportunities).

In Analyses Phase, a Pareto Chart (ranked histogram) of the data stratified by building allowed the team to identify which buildings had the most total maintenance hours. According to the histogram, they got some analyses results and then, using their improved understanding of the problem, the team re-scoped the project and re-stated the problem statement. The team collected additional information from the equipment owner, the customer and the maintenance planner responsible for scheduling maintenance activities. This analysis led the team to four primary causes of defects.

In Improve Phase, they brainstormed again to identify specific improvements for the issues they had identified.

In Control Phase, they get results that, the projected improvements indicate: DPMO will fall and the sigma value will increase and by this way, Ford Motor Company will save in direct maintenance labor.

Knowles, Johnson, & Warwood (2004), looks at a successful application of the Six Sigma improvement methodology within a UK(The United Kingdom) confectionery plant of a major food producer. The business in question faces a challenge to reduce the cost of its products to bring them in line with the cost of similar products made at other European factories.

The project was selected as suitable based upon the impact of the process performance on key business measurable and upon the internal costs of the organization as driven by the three principal problems which were selected before. Sweet thickness was chosen as the key quality characteristic as it clearly drove the three major losses noted and a project team was chosen to examine this key quality characteristic and improve the process which was named as Brand X.

In Define Phase, team generated a cause and effect diagram to establish the effects of sweet size variations on the process. Then costs of sweet size variability were defined according to three major principal problems. Finally, the agreed process flow chart was formed.

In Measure Phase, they looked at the amount of variation at sweet. X bar and R charts were used for actual sweet thickness measurements from the Brand X process, over a period of two weeks with a histogram of the raw data. Conclusion of this work, they got some explanations about stability and variations of process and they decided to focus on special causes. A scatter plot of sweet size against weight confirmed this, with the plot “flattening off” at the top. They redefined the problem, the group started with a brainstorm, following the process flow and identifying where the problem could affect the product. This was then collated into a cause and effect diagram and the team was split into groups, each of which investigated one segment of the potential problem.

In Analyze Phase, having derived that problem is a special cause of Brand X sweet size variation and identified the potential sources of air in the sweets, the team conducted a series of confirmation experiments to verify that problem had been found and that these had an impact on size variation. These are examined by control charts and histogram.

In Improve Phase, some modifications were done about process problems. Experiments were established and capability study proved that the works done to improve common causes had been very worthwhile.

In Control Phase, all changes to process have been fully integrated into the training regime and the process documentation, including detailed control plans and visual controls. SPC (Statistical Process Control) is now applied to provide predictive control. The financial savings noted below have been verified over a 12 month operating period.

Banuelas, Antony, & Brace (2005), is also examined Six Sigma in manufacturing. In their research, the primary objective of Six Sigma in this case is waste reduction. To prioritize potential areas of improvement using Six Sigma, the team employed a cause and effect matrix. As a result, project team select three Six Sigma projects and this paper focus on one of these projects which is about identifying, quantifying and eliminating the source of variation that leads to failure due to spindle changes by the re-winder machine.

In Define Phase, definitions which identify are made step by step. On these steps are identified by road map. By critical to cost tree graph, depicts how generic business goals cascade into more specific potential Six Sigma projects.

In Measure Phase, process mapping which was generated by using SOP (Standard Operating Procedure) format provided a picture of the steps that are needed to create the output and process. Process Capability, indicated the current status of the process performance, run chart was created for the fraction of non-conforming chop-overs. To recognize any possible trend in failures within the re-winder process, a Pareto plot of defects was generated. As the box plot illustrated, the cut cycle time appeared lower than that of the failures. For a successful chop-over versus an unsuccessful chop-over, a hypothesis test was carried out. Gauge R&R (Repeatability and Reproducibility) analysis was carried out to assess how much variation is associated with the measurement system. Cause and effect analysis was carried out to illustrate the various causes that affect the re-winder performance.

In Analyze Phase, main effects plots were employed to log data means for different affects. The multi-vary chart was carried out to determine the interaction between predictors. Having carried out analyzing the data with the aid of multi-vary charts, hypothesis test, gauge R&R, basic descriptive statistics and main effects plot, some predictors were discarded for further analysis and others were selected to form part of the vital few.

In Improve Phase, the variations were estimated by the square root of the mean square error term in the ANOVA (Analyze of Variance) table. The dimensions of the variables were given by the vector loop diagram. After these, the improved solution was implemented during the control phase, and is described in the next section.

In Control Phase, actual process capability was measured to control process improvement and a control plan, which indicates the target values, specifications limits and standard deviation expected for this critical to quality characteristic, was put in place.

Sekhar, & Mahanti (2006), is examined about Six Sigma application in manufacturing which is about to improve air quality in a foundry. Previous examinations defined that air quality has an effect about the efficiency of employees and affected the environmental health of people living around the foundry. Due to these reasons this Six Sigma application was done.

In Define Phase, the problem was illustrated and some air pollution measurements were done and the goal was illustrated that to reduce the particulate and gaseous pollutants emission.

In Measure Phase, related measurements about the particulate and gaseous pollutants emission were done by using different statistical techniques.

In Analyze Phase, the potential causes behind the high emissions were first identified using cause and effect diagram and Failure mode and Effect Analysis. In this phase the data collected was analyzed to classify the potential causes of high emissions and quality of raw material and improper functioning of the Venturi Scrubber were found to be the major causes behind the high emissions.

In Improve Phase, an improvement plan was chalked out based on the results of the analysis phase. On using good quality foundry grade coke containing low sulphur content, clean scraps and calcium hydroxide as scrubbing liquid, sulphur dioxide emissions were found to reduce and which indicated the need for further improvements. The efficiency of the Venturi Scrubber was evaluated using the simulation model using different values of pressure drop of water across the Venturi Scrubber and liquid-to-gas ratio. After simulated values were supplemented by real measurements and a new flow diagram was created and applied.

In Control Phase, simulation verifying was continued and simulation values were compared with real values as a control and articulate emission were registered for control the applications.

Kumar, Antony, & Madu (2006), research deals with the reduction of casting defects in an automotive engine which is also about manufacturing sector. DMAIC Methodology was used as the road map for problem solving in this case study.

In Define Phase, the goal statement of the project defined by the team members was the reduction of casting defects that would result in an immense reduction in the Cost of Poor Quality (COPQ). After performing a number of brainstorming exercises and using a multi-voting method, the team members arrived at the conclusion that the cause of defect was the porous core used for the casting process. The team focused on the following processes of the porous core for enhancing customer satisfaction and reducing COPQ in the foundry: sand preparation, core making process, wash preparation and coating.

In Measure Phase, starts with a process mapping that provides a picture of the steps needed to create the process. The cross-functional team brainstormed the reasons for the porous core causing casting defects in the engine manufacturing process. After that, team created a cause and effect diagram for porous core. Then, data collection plan was established to focus on the project output and also to carry out the standard setting exercise. A Gage Repeatability and Reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether the measurement system was capable or not. The baseline process capability (*Cpk*) was also established in this phase and clearly indicates that process performance is poor and it clearly needs improvement.

In Analysis Phase, data pertaining to factors affecting the response were collected over a period of 45 days from different shifts in the day. Data was not used only to determine relationship between the process parameters and the response but also to determine the direction of process improvement. The improvement goal of the project is defined statistically through benchmarking with an automotive industry in the U.S.A. (The United States of America). A simple regression analysis is performed to determine the significance of the process parameters.

In Improve Phase, it was decided to perform a design experiment with the above three process parameters identified from the analysis phase. A 2^3 full factorial design was chosen so that both the main effects and the interaction effects among the parameters could be investigated.

In Control Phase, a complete database is prepared to maintain the improvement to the result. Run charts for the depth of the porous core were constructed prior to and after improvements were made to the process. The purpose of the run charts was to analyze variability in the porous core around its mean value. The process capability has improved, showing a tremendous improvement in the production system.

2.6.2 Researches in Service

Although, Six Sigma approach has predominantly been used in manufacturing sector, there are many Six Sigma applications in service sector. In these applications, service companies get significant achievements about customer satisfaction, saving money, reduction of service time etc.

Heuvel, Does, & Vermaat (2004), explicates three Six Sigma projects in a Netherland hospital.

The first project was applied to reduce the length of stay of Gynecology patients.

In first project's Define Phase, financial benefits, project team and the objectives were illustrated and observed patients who had to undergo an abdominal uterus extirpation (AUE) or a vaginal uterus extirpation (VUE) were determined.

In Measure Phase, CTQ characteristic were defined and observations were done by using patients.

In Analyze Phase, previous year's data were used. The average stay time of patients and standard deviations were indicated and according to actual values and target financial benefit which was illustrated at define phase, the target average stay time of patients and standard deviations were determined. Cause and Effect Diagram and FMEA were used to list the factors influencing the length of stay.

In Improve Phase, improvement methods were found.

In Control Phase, all of the mentioned improvements were implemented and considerable reduction was seen at average stay time and standard deviation.

The Second Project was objected to shorten the preparation time of intravenous medication.

In Define Phase, financial benefits were estimated and project teams were chosen.

In Measure Phase, CTQ characteristic was illustrated as the preparation time of one dose of intravenous medication. Total preparation time was observed by stopwatch. A Gauge R&R study was carried out on the stopwatches.

In Analyze Phase, collected data were examined and average preparation time and standard deviation were revealed. Brainstorming method was used to find the relevant factors that influence the preparation time.

In Improve Phase, an improvement was determined and carried out.

In Control Phase, a new program was scheduled and executed and financial benefits were controlled.

The Last Project was objected to reduce the number of mistakes on the invoices of temp agencies.

In Define Phase, CTQ, financial benefits and project team were defined.

In Measure Phase, some critical criteria were checked; declaration forms and invoices were investigated.

In Analyze Phase, declaration forms and invoices were analyzed and classified according to correction of forms and invoices. Brainstorming was done to reduce incorrect parts.

In Improve Phase, improvements methods were determined about failures.

In Control Phase, a new procedure and a new worksheet which was revised by improvement of failures at declaration form was published.

Pandey (2007), was also researched about service sector and in research, conducted in a multi national bank located in the National Capital Region (NCR) of India. Implementation of Six Sigma had facilitated the HR function to perform this task better in this research.

Define Phase started with identification of the services provided by the organizational function to internal or external customers. Services are than prioritized in terms of their criticality for satisfaction of customers. Project selection is done based on: customer satisfaction survey, Pareto diagram, benchmarking and prioritization voice of customer.

In Measure Phase, process mapping clarified who were the customers and what were their priorities. Critical to process (CTP) questions were identified by delineating sub processes. Two measurements were identified: Learning and development index and the cost per man-hour training.

At Analyze Phase, the main objective of analysis was to find out the root cause of undesired quality level. Sources of variations were found through different statistical tests like chi-square, ANOVA etc. On the basis of the findings of these techniques brainstorming sessions were conducted within the team. Fishbone analysis was conducted to understand the cause and effect relationship of the defect in the process.

In Improve Phase, action plans were made for rectifying the root causes. Improvement started with prioritizing the root causes to be worked upon. Persons responsible for fixing the cause were communicated. Process capability at Six Sigma level was decided by process owners.

In Control Phase, the before and after analyses was conducted. Process Capability was used to reveal improvement level.

Kumar, Wolfe, & Wolfe (2008), researched to analyze the credit initiation process for mid-level corporate credit card customers at a major US financial services operation by application of Six Sigma DMAIC Methodology.

In Define Phase, a process in need of improvement which is the steps of credit approval process was identified. A process flow chart was provided by the company to illustrate the steps of the current credit approval process.

In Measure Phase, five months of historical data was collected on the process through a database that monitors progress of the Credit Initiation Team. The data collected ranges from how many days it took to complete each step in the process to who was involved with each step.

In Analyze Phase, the histogram showed that most credits were approved. The cause and effect diagram used to determine the potential causes. To determine the impact pending a request had on the number of days to approve a request, a one-way ANOVA test was conducted to illustrate correlation. The results of the test indicated that there was a moderate correlation between pending requests and greater days to approve a request.

In Improve Phase, it was clear that the two areas of the process in most need of improvement were the sales team and the approval stages. A cause and effect diagram was used to identify these failures. After failures were outlined, poke yoke were used for improvements of suggested areas and after poke yoke applications revised process flow chart was published.

In Control Phase, the management team met monthly to review progress and compliance with the changes and progress discussed for a long term period. By this project, bottlenecks were found and improved.

Kukreja, Ricks Jr., & Meyer (2009), Six Sigma project was undertaken to analyze the performance of a university's students in the accounting section of the ETS (Educational Testing Service) major field examination in the business.

In Define Phase, Six Sigma project was started with construction of team members. Then, the gaps and problems were addressed and they used the problem worksheet to define all relevant questions regarding problem definition and appropriateness of the project for the Six Sigma methodology.

In Measure Phase, the Process Maps and Cause and Effect Matrix were used to described process and problem. The high level and the low level process maps were used on this project. The high level describes the process in one step and documents the main inputs and outputs in the overall process. Inputs to the process were then categorized as controllable or uncontrollable, represented as *c* or *u* in the process map. Controllable inputs were variables that could be changed at the direction of the process owner to see the effect on output variables. Uncontrollable inputs were variables that have an impact on the output variables but were difficult or impossible to control. The process map also leaded to the Cause and Effect Matrix. Then each step in the process and all of the controllable inputs for each step were listed in the Cause and Effect Matrix.

In Analyze Phase, FMEA (Failure mode and effect analysis) was used to analyze the output from Cause and Effect Matrix as an input. To complete the FMEA, a ranking regarding particular process failures was developed. Based on ratings, a risk priority number was assigned to each input during the FMEA. Inputs with high RPNs (Risk Priority Numbers) were critical to the process and became the basis for improvement strategies.

In Improve Phase, recommendations were issued and applied about identified process failures.

In Control Phase, a control plan was prepared and RACI (responsible, accountable, consultation and informed) matrix was used to identify person responsible at control plan. Finally, an improvement was seen at next ETS but later variability was measured. After examination, the explanation of variability was defined by effect of Hurricane Katrina. As a result, in all three years following the Six Sigma project indicates that the project was successful.

2.6.3 Researches in Construction

Construction sector has been remained behind the other sectors in terms of quality techniques, application of these techniques and researches of these applications. Although, applications and researches about Six Sigma are not as much as other sectors, there are several applications and researches about Six Sigma in construction sector.

Pheng, & Hui (2004), were also researched about Six Sigma Approach in a construction sector which was examined application in the Housing and Development Board (HDB) in Singapore is presented in this section to highlight its implementation processes. This case study will first concentrate on the implementation process of the Six Sigma initiative in the HDB.

In Define Phase, the implementation is started with training of team members. Then pilot projects and staff roles were determined. The criteria for choosing the three pilot projects were first that these projects have to be representative of the diverse operations of the HDB. Second, from customer feedback, the areas that recorded the highest number of unsatisfactory feedback were also identified. From these criteria, the following three pilot projects were chosen: First quality of building product. This project involved improving the quality of a building component. Business partners were involved in this project. Secondly, facility reliability measurement of the mechanical systems of the HDB flats and the last one, transaction service which is involved reducing the cycle time of counter service and finally, the duration of the projects was lengthened.

Afterward, The Construction Quality Assessment System (CONQUAS), assessment consists of three components: First, structural works, second architectural works and mechanical and electrical (M&E) works.

A CONQUAS score of 100 points is theoretically possible for a perfect building. A building is assessed based on workmanship standards achieved through site inspection. Unlike structural works and M&E works which are predominately concealed, Architectural works deal mainly with the finishes and components. This is also the part where the quality and standard of workmanship are most visible, thus giving rise to the possibility of more complaints by HDB flat-dwellers.

As it is impractical to assess all elements in a building, CONQUAS uses a sampling system for the assessment. Sampling is based on the gross floor area of a building to ensure that the assessment adequately represents the entire building. CONQUAS assessors, undertake scoring on the works that are inspected for the first time. When an assessed item does not comply with the corresponding CONQUAS specified standards, it is considered failed and a ‘‘X’’ will be noted in the assessment. A ‘‘√’’ is indicated for an item meeting the standards, and a ‘‘-’’ indicates that the item is not applicable. The score is computed based on the number of ‘‘√ ’’ over the total number of items assessed and a score sheet is used to control completion of works. The CONQUAS score sheets of Contractor A, relating to the recently completed project were then subject to Six Sigma analysis. After, sigma of process was calculated by using DPMO.

Over a period of 10 months, special attention was paid by Contractor A to ensure that its on-going building projects were closely supervised to meet the quality standards specified in CONQUAS for internal finishes. In addition, measures were taken to ensure that only skilled tradesmen were employed in the works. Contractor A also reviewed the quality track records of its trade subcontractors to ensure that only those with good past performance were employed. The same review was also made for the suppliers where products (such as doors, windows, and components) were used in the projects.

Following the completion of the on-going projects at the end of 10 months, the internal finishes were assessed for their CONQUAS points. This assessment exercise also provided the data for computing the sigma of completed works to ascertain if the improvement measures taken by Contractor A have indeed helped to raise the sigma. Based on the checks in the equivalent sigma for DPMO is achieved higher than the planned sigma level set earlier for Contractor A. By achieving a higher sigma level, the corresponding CONQUAS scores for internal finishes were expected to rise accordingly. With improvements in both sigma and CONQUAS scores, the probability of HDB flat-dwellers to complain about defects relating to internal finishes was further eliminated.

Stewart, & Spencer (2006), demonstrate the potential of Six Sigma to achieve Continuous Process Improvement (CPI) in construction and to highlight the benefits of introducing a structured assembly-line doctrine to construction processes. The case study was based on a PIP (process improvement project) for a contract in the United Kingdom. The contract, Contract 105 (C105) of the Channel Tunnel Rail Link (CTRL) includes the construction of an extension to the existing St Pancras Station, London.

In Define Phase, project was defined as; to improve the construction of raised platform beams with the explicit aim of identifying particular activities that were causing defects. The goal was to reduce the delays to the beam operation, reducing the forecast delay. The primary metric was defined as the gap in the beam performance measured on a weekly basis. The secondary metric was defined as the gap in the cost performance.

In Measure Phases, a cause-and-effect analysis was carried out with the process owners to establish the more general causes of delays to the beam construction process. Progress charts were produced on a weekly basis and issued to the project participants and the head office. The team's objective was to establish a theoretical performance for the construction of a single platform beam (beams were poured in 15m lengths). The start, end time and date were recorded by the beam field engineer on a data collection sheet. This information was then entered into a workbook so that performance could be measured and monitored to identify what processes were causing delays.

In Analyze Phase, the analysis used the latest revision of the construction to show how the amount of formwork and false-work used would affect theoretical production rates.

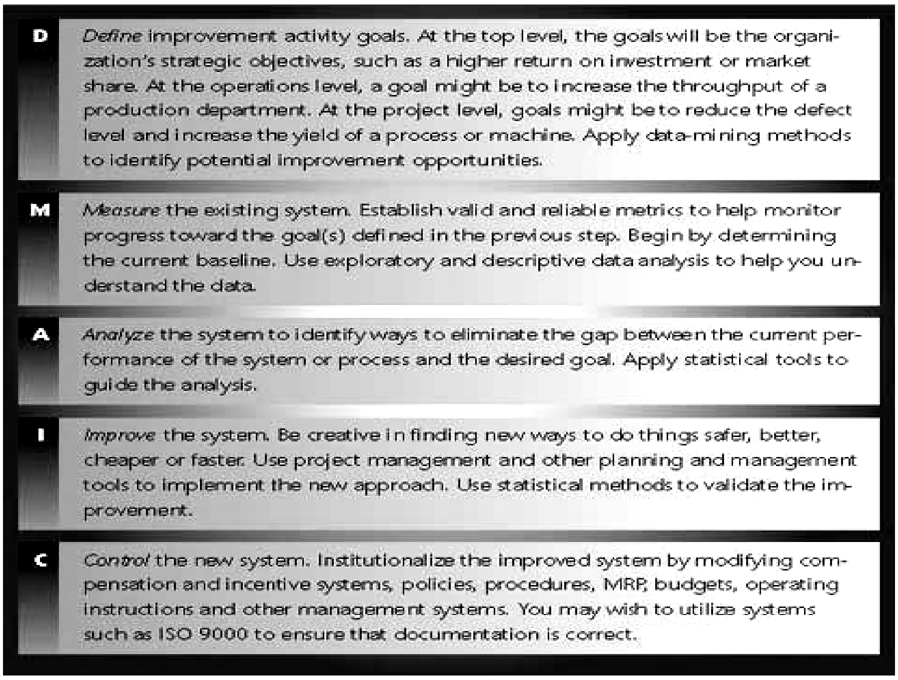
In Improve Phase, the previous phases drew the PIP team's attention to three areas relating to the construction of platform beams where improvements could be made and subsequent time/cost savings realized. These areas of improvements included: (1) pre-beam activities; (2) efficiency of beam construction based on the duration of construction; and (3) equipment levels (i.e. formwork). During meetings, the team stressed the importance of formal communication channels between department heads and foremen to ensure that when future problems were identified, they could be remedied efficiently and effectively. Finally, an analysis on the current levels of equipment used was conducted and it was recommended to purchase an additional set of false-work (tables) and formwork.

In Control Phase, to sustain improvements, the team monitored the construction of the beams with the charts developed in the measure and analysis phases of the improvement process. A review of these charts indicated that there had been noticeable improvements in most of the activities specifically, less variability in activity durations. The major findings and recommendations from this case study are as follows: (1) the most significant factor influencing the performance of beam construction is the availability of the site; (2) coordination of the construction activities through the use of monitoring and projection tools enabled the teams to work together, rather than independently; (3) continued collection of performance data (i.e. control phase) helped to highlight areas where future process improvements could be made; and (4) project teams should be measured in a different way, whereby they were rewarded for the handover of a defect-free structure to the next team.

CHAPTER THREE
DMAIC METHODOLOGY

3.1 What is DMAIC?

Six Sigma's magic doesn't lie in statistical or high-tech razzle-dazzle. Six Sigma relies on tried-and-true methods that have been around for decades. In fact, Six Sigma discards a great deal of the complexity that characterizes total quality management (TQM). By one expert's count, there are more than 400 TQM tools and techniques. Six Sigma takes a handful of these methods and trains a small cadre of in-house technical leaders, known as Six Sigma Black Belts, to a high level of proficiency in the application of these techniques. To be sure, some of the methods used by Black Belts, including up-to-date computer technology, are highly advanced. But the tools are applied within a simple performance-improvement framework known as DMAIC, or define-measure-analyze-improve-control, which is analogous to the older TQM model known as plan-do-study-act. Anyone with more than the most cursory exposure to Six Sigma is familiar with the DMAIC cycle (Pyzdek, n.d.) which is illustrated at Figure 3.1.



D	*Define* improvement activity goals. At the top level, the goals will be the organization's strategic objectives, such as a higher return on investment or market share. At the operations level, a goal might be to increase the throughput of a production department. At the project level, goals might be to reduce the defect level and increase the yield of a process or machine. Apply data-mining methods to identify potential improvement opportunities.
M	*Measure* the existing system. Establish valid and reliable metrics to help monitor progress toward the goal(s) defined in the previous step. Begin by determining the current baseline. Use exploratory and descriptive data analysis to help you understand the data.
A	*Analyze* the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. Apply statistical tools to guide the analysis.
I	*Improve* the system. Be creative in finding new ways to do things safer, better, cheaper or faster. Use project management and other planning and management tools to implement the new approach. Use statistical methods to validate the improvement.
C	*Control* the new system. Institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, MRP, budgets, operating instructions and other management systems. You may wish to utilize systems such as ISO 9000 to ensure that documentation is correct.

Figure 3.1 DMAIC framework (Pyzdek, n.d.)

The flowchart for DMAIC quality improvement process is figured at Figure 3.2.

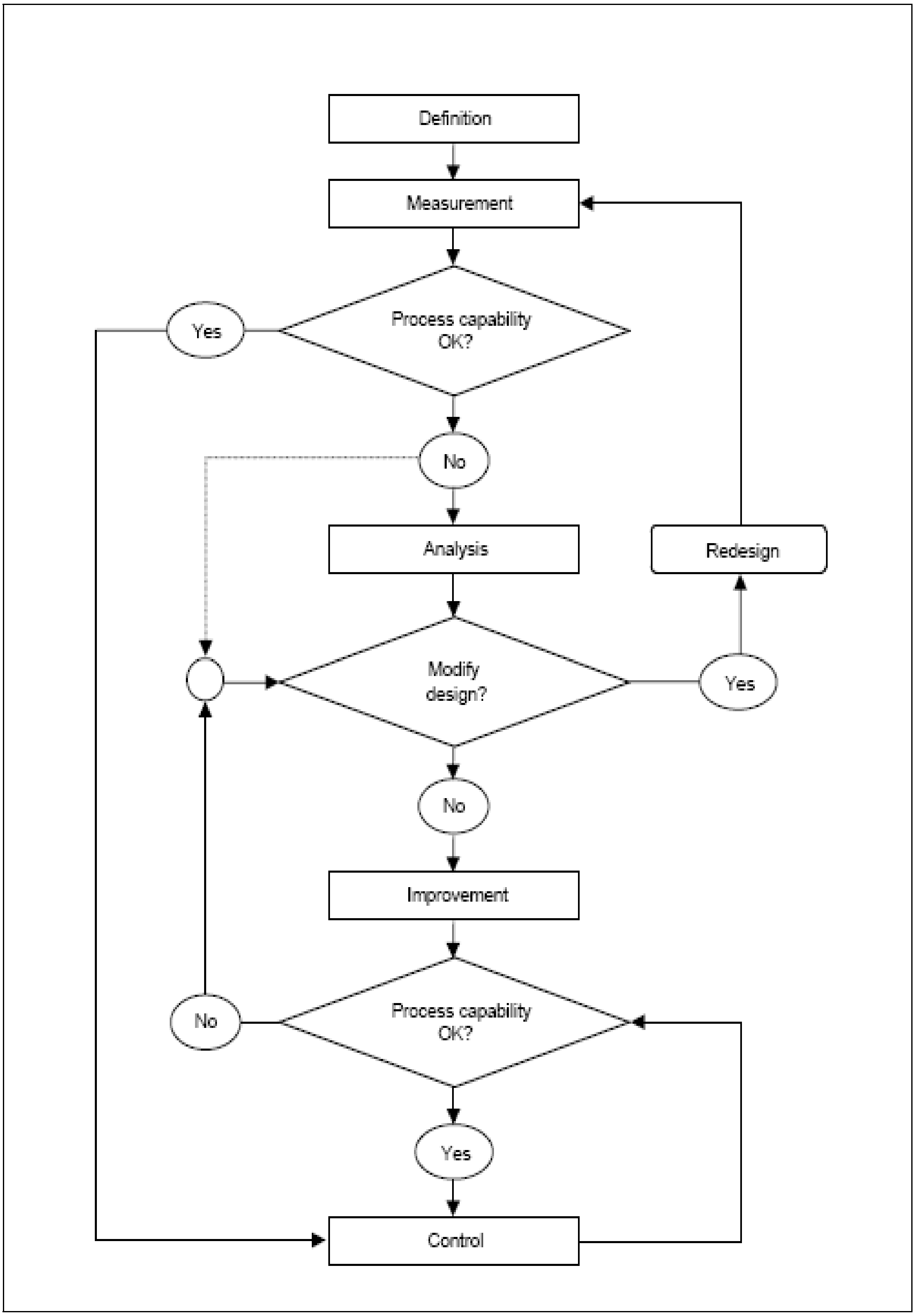


Figure 3.2 Flowchart DMAIC (Park, 2003, pg. 40)

The major activities and applications of DMAIC methodology may be explained as follows:

3.1.1 Define Phase

This phase is concerned with identification of the process or product that needs improvement. It is also concerned with benchmarking of key product or process characteristics of other world-class companies (Park, 2003, pg. 38).

The purpose of the Define phase is to clearly identify the problem, the requirements of the project and the objectives of the project. The objectives of the project should focus on critical issues which are aligned with the company's business strategy and the customer's requirements. The Define phase includes (Summary of the six-sigma define, 2008):

- Define customer requirements as they relate to this project. Explicit customer requirements are called CTQ characteristics;
- Develop defect definitions as precisely as possible;
- Perform a baseline study (a general measure of the level of performance before the improvement project commences);
- Create a team charter and champion;
- Estimate the financial impact of the problem; and
- Obtain senior management approval of the project

In the Define phase, you need to determine which opportunities will provide the biggest payoff for our efforts. Part of this task involves describing the current state of various metrics. You are interested in learning how various metrics behave. Are there any important trends? Are the data relatively stable or are there outliers? What do the statistical distributions look like? Are the distributions what we'd expect from this process (Pyzdek, 2003b, pg. 97)?

Some tools and techniques to consider during the Define phase include the following: (Pyzdek, 2003b, pg. 97-98)

- Flowcharts
- Process Mapping
- Check sheets
- Pareto analysis
- Cause-and-effect diagrams
- Seven management tools for quality control (7M tools)
- Data mining: exploring information contained in the enterprise data warehouses using automated or semi-automated means

3.1.2 Measure Phase

This phase entails selecting product characteristics; i.e., dependent variables, mapping the respective processes, making the necessary measurement, recording the results and estimating the short and long-term process capabilities (Park,2003, pg. 38).

Goal is to pinpoint the location or source of the problem as precisely as possible by building a factual understanding of existing process conditions and problems. Having this knowledge will assist you in narrowing the range of potential causes that are needed to investigate in the Analyze phase. Therefore, the important function of the Measure phase is to establish a baseline capability level (Step #2, n.d.).

The purpose of the Measure phase is to fully understand the current performance by identifying how to best measure current performance and to start measuring it. The measurements used should be useful and relevant to identifying and measuring the source of variation. This phase includes (Summary of the six-sigma measure, 2008):

- Identify the specific performance requirements of relevant CTQ characteristics;

- Map relevant processes with identified Inputs and Outputs so that at each process step, the relevant Outputs and all the potential Inputs (X) that might impact each Output are connected to each other;
- Generate list of potential measurements
- Analyze measurement system capability and establish process capability baseline;
- Identify where errors in measurements can occur;
- Start measuring the inputs, processes and outputs and collecting the data;
- Validate that the problem exists based on the measurements;
- Refine the problem or objective (from the Analysis phase)

3.1.3 Analyze Phase

This phase is concerned with analyzing and benchmarking the key product/process performance metrics. Following this, a gap analysis is often undertaken to identify the common factors of successful performance; i.e., what factors explain best-in-class performance. In some cases, it is necessary to redefine the performance goal (Park, 2003, pg. 39).

In the Analyze phase, the measurements collected in the Measure phase are analyzed so that hypotheses about the root causes of variations in the measurements can be generated and the hypothesis subsequently validated. It is at this stage that practical business problems are turned into statistical problems and analyzed as statistical problems. This includes (Summary of the six-sigma analyze, 2008):

- Generate hypotheses about possible root causes of variation and potential critical Inputs (X’s);
- Identify the vital few root causes and critical inputs that have the most significant impact; and
- Validate these hypotheses by performing Multivariate analysis.

In the Analyze phase of the Six Sigma project cycle, you must quantify the existing process to determine how best to achieve the process improvement goals. Tools and techniques useful during the analyze phase include: (Pyzdek, 2003b, pg. 119)

- Run charts
- Descriptive statistical analysis (central tendency, spread, distribution, outliers)
- Exploratory data analysis (box plot comparisons, stem-and-leaf)
- SIPOC
- Analytic data analysis (time series, SPC)
- Data mining: analysis of information contained in the enterprise data warehouse using automated or semi-automated means
- Process capability analysis
- Process yield analysis
- Scatter plots
- Correlation and regression analysis
- Categorical data analysis
- Nonparametric methods

3.1.4 Improve Phase

This phase is related to selecting those product performance characteristics which must be improved to achieve the goal. Once this is done, the characteristics are diagnosed to reveal the major sources of variation (Park, 2003, pg. 39).

The Improve phase focuses on developing ideas to remove root causes of variation, testing and standardizing those solutions. This involves: (Summary of the six-sigma improve stage, 2008)

- Identify ways to remove causes of variation;
- Verify critical inputs;

- Discover relationships between variables;
- Establish operating tolerances which are the upper and lower specification limits (the engineering or customer requirement) of a process for judging acceptability of a particular characteristic, and if strictly followed will result in defect-free products or services;
- Optimize critical inputs or reconfigure the relevant process.

Some of the tools commonly used in the Improve phase are shown below: (Improve, 2009)

- Stakeholder analysis
- Mistake proofing (poka yoke)
- WHY
- 7 wastes
- Design of experiments (DOE)
- Takt time
- Line balancing
- SPC charts.

3.1.5 Control Phase

This last phase is initiated by ensuring that the new process conditions are documented and monitored via statistical process control methods. After the "settling in" period, the process capability is reassessed. Depending upon the outcome of such a follow-on analysis, it may become necessary to revisit one or more of the preceding phases (Park, 2003, pg. 39).

The Control phase aims to establish standard measures to maintain performance and to correct problems as needed, including problems with the measurement system. This includes (Summary of the six-sigma control stage, 2008):

- Validate measurement systems;
- Verify process long-term capability;
- Implement process control with control plan to ensure that the same problem don’t reoccur by continually monitoring the processes that create the products or services.

Below is a list of tools commonly used in this phase: (Control, 2009)

- SPC Charts
- Assessing Final Process Capability
- Total Productive Maintenance (TPM)
- Revised FMEA
- Mistake Proofing
- Control Plan
- Verify Financial Savings.

3.2 DMAIC Tools

3.2.1 Cause and Effect Diagram

Its primary purpose is to show the relationship between a given effect and all identified causes of that effect (Xu, 2001).

When utilizing a team approach to problem solving, there are often many opinions as to the problem's root cause. One way to capture these different ideas and stimulate the team's brainstorming on root causes is the cause and effect diagram, commonly called a fishbone. The fishbone will help to visually display the many potential causes for a specific problem or effect. It is particularly useful in a group setting and for situations in which little quantitative data is available for analysis (Simon, n.d.).

The cause-and-effect diagram is used where it is required to brainstorm and show pictorially cause-and-effect relationships and the root causes of a problem. It is frequently called a fishbone diagram (because of its shape) or an Iskikawa diagram (after its creator) (Truscott, 2003, pg. 154).

While using this diagram, it is important to list all possible causes of a problem, no matter how unimportant or trivial they may seem. When the cause and effect diagram is properly prepared, it can be a very useful tool for analyzing current and optimum situations as well (Villarreal & Kleiner, 1997).

When constructing a cause-and-effect diagram, it is often appropriate to consider six main causes that can contribute to an outcome response (effect): so-called 5M1E (man, machine, material, method, measurement, and environment) (Simon, n.d.). Figure 3.3 shows an example of a cause and effect diagram.

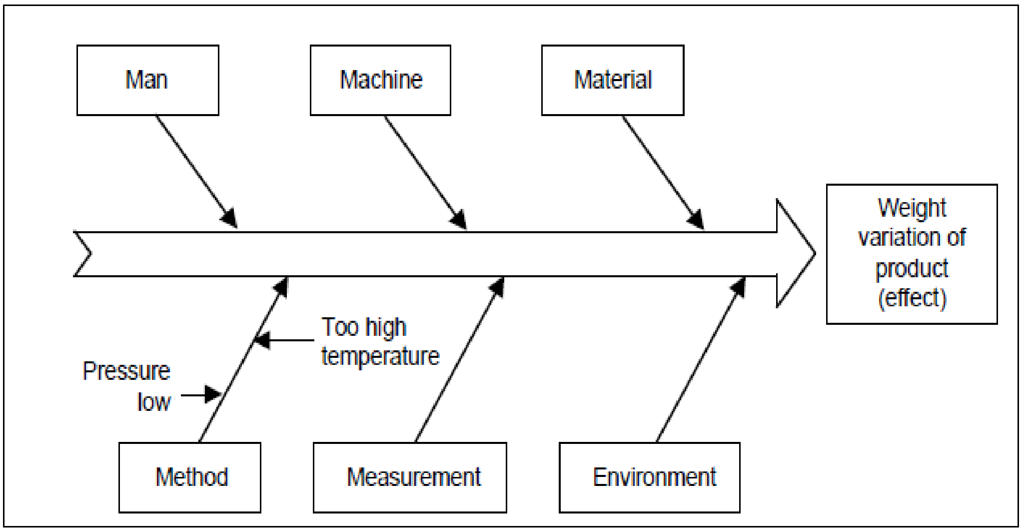


Figure 3.3 An example of a cause& effect diagram (Park, 2003, pg 75)

The aim is to refine the list of causes in greater detail until the root causes of that particular main cause are established. The same procedure is then followed for each of the other main causes (Park, 2003, pg. 75).

3.2.2 Check Sheet

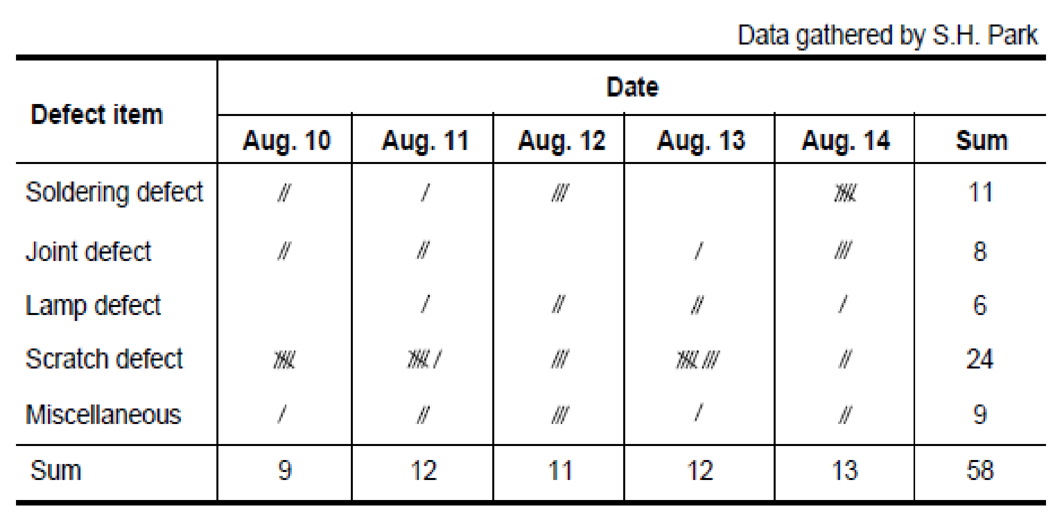
The check sheet is used for the specific data collection of any desired characteristics of a process or product that is to be improved (Park, 2003, pg. 75).

Checklists can be useful in collecting maintenance data or describing frequent checks that must be made in order to ensure an effective and trouble free running of equipment. Examples of checklists that can be used in maintenance planning and control are for (Duffua, &Ben-Daya, 1995):

- Collecting data for histograms;
- Planning maintenance jobs;
- Auditing a maintenance system;
- Reviewing spare parts;
- Major equipment maintenance;
- Work sampling;
- A foreman job description;
- The tool room;
- Preparation and cleaning after jobs;
- Preventive maintenance tasks.

As a result, check sheets are the way of collecting data and they can be used at measure phases of DMAIC methodology for this. The Table 3.1 shows an example of check sheet.

Table 3.1 An example of check sheet (Park, 2003, pg. 76)



Data gathered by S.H. Park

Defect item	Date					
	Aug. 10	Aug. 11	Aug. 12	Aug. 13	Aug. 14	Sum
Soldering defect	//	/	///		𝍸	11
Joint defect	//	//		/	///	8
Lamp defect		/	//	//	/	6
Scratch defect	𝍸	𝍸 /	///	𝍸 ///	//	24
Miscellaneous	/	//	///	/	//	9
Sum	9	12	11	12	13	58

3.2.3 Pareto Chart

The Pareto Chart was introduced in the 1940s by Joseph M. Juran, who named it after the Italian economist and statistician Vilfredo Pareto, 1848–1923. It is applied to distinguish the “vital few from the trivial many” as Juran formulated the purpose of the Pareto chart (Park, 2003, pg. 81).

The Pareto Chart is a special form of the Bar Chart, helping the user to identify the most common occurrences of causes of a problem. It is used to stratify data into groups from largest to smallest (Pyzdek, 2003a, pg. 259). The Figure 3.4 shows an example of Pareto Chart.

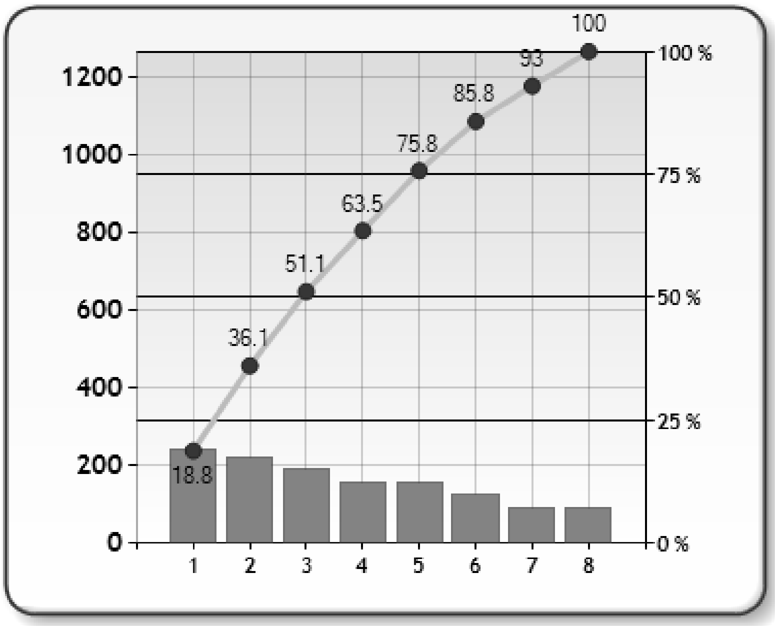


Figure 3.4 An example of pareto chart (Pareto,nd)

The procedure is (Truscott, 2003, pg. 153):

- Select the concern to be rank ordered and the measure (e.g. Frequency, cost) and gather data;
- List the elements from left to right on the horizontal axis in order of size;
- Set up an appropriate vertical scale on the left-hand side and above each classification draw a rectangle whose height represents its size;

- Set up a 0–100 % scale on the right-hand side and draw a line from the top of the tallest bar, moving upward, on a cumulative basis from left to right.

3.2.4 Scatter Diagram

The scatter plot provides a way of viewing a data set to detect trend, to spot operating regions or to explore relationships (correlation, cause-effect connections) between variables (He, Staples, Ross & Court, 1996).

In general, it may be applied to carry out the following analyses (Duffua & other., 1995):

- Trend analysis.
- Correlation or pattern analysis.
- Particularly in maintenance, it can utilized to find the following:
- Correlation between preventive maintenance and quality rate.
- Correlation between level of training and backlog.
- Correlation between level of training and repeat jobs.
- Correlation between vibration level and quality rate.
- Correlation between preventive maintenance and downtime.
- Downtime trend.
- Trend of maintenance cost.
- Trend of crafts productivity.
- Backlog trend.
- Equipment availability trend.

Finally, a scatter diagram is a graphical representation of the relationship between two characteristics of the same process. If the plotted points on the diagram show any trends or consistent shape, it suggests that there is a relationship between the two characteristics. If, however, the points are random and scatter all over the diagram, no relationship is believed to exist (Villarreal & other, 1997). The Figure 3.5 shows an example of scatter diagram.

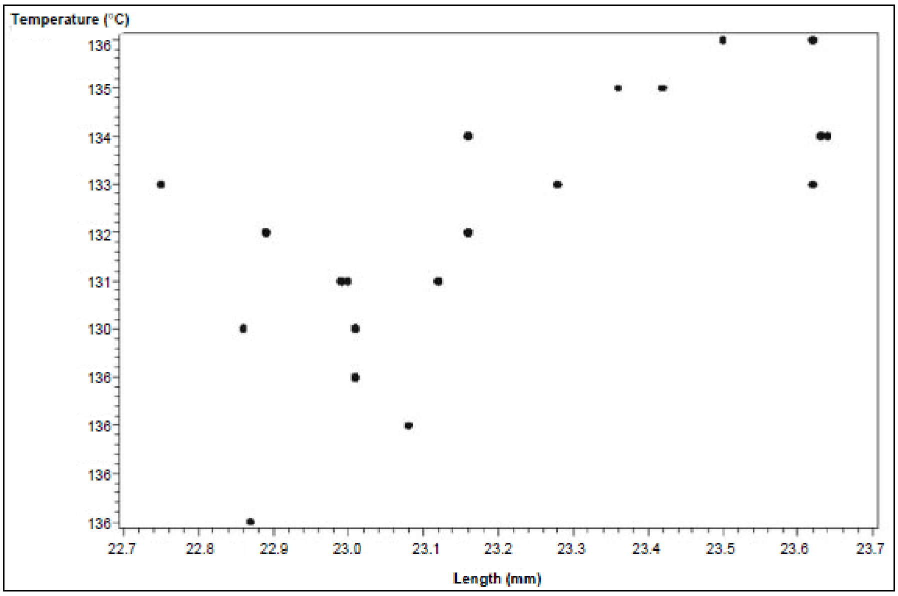


Figure 3.5 An application about scatter diagram (Park, 2003, pg. 84)

3.2.5 Histogram

A histogram is a graphical representation of frequency of occurrence versus data points or a class that represents a set of data points. The histogram makes it easy to find the shape, the central value and the extent of dispersion. Any basic book on statistics or quality control explains how to construct a histogram (Duffua & other., 1996).

A histogram is a specialized type of bar chart. Individual data points are grouped together in classes, so that you can get an idea of how frequently data in each class occur in the data set. High bars indicate more points in a class, and low bars indicate less point (Histograms, n.d.)

To create a histogram when the response only “takes on” certain discrete values, a tally is simply made each time a discrete value occurs. After a number of responses are taken, the tally for the grouping of occurrences can then be plotted in histogram form (Park, 2003, pg. 80). Figure 3.6 shows example of histogram.

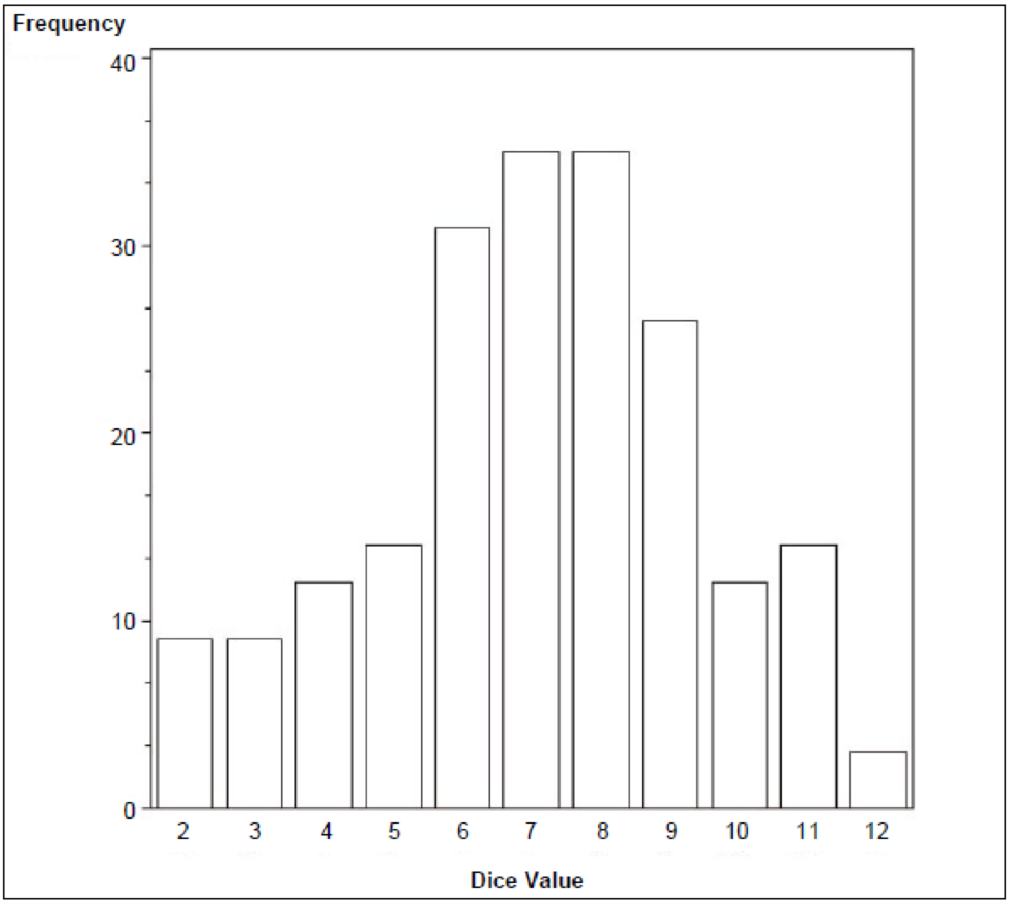


Figure 3.6 A histogram example (Park, 2003, pg. 81)

3.2.6 Control Charts

These charts are used to decide whether a process has achieved a state of statistical control and to maintain current control of a process (Yang, 1997).

Upper control and lower control limits are used to show variations from specification. Within the control limits, performance will be deemed to be acceptable. The aim should be to reduce the control limits over time, and thus control charts are used to monitor processes and the data gathered from the charts should be used to force never-ending improvements. These types of charts might also be known as Tolerance charts (Basu, & Wright, 2003, pg. 182).

Control charts are the heart of SPC and they can be applied in many areas of maintenance for quality improvement. Examples of these diverse applications are control of (Duffua & other., 1996):

- Monthly backlog;
- Downtime of major equipment;
- Job completion time for certain jobs;
- Equipment availability;
- Equipment quality rate;
- The number of breakdowns of equipment.

Control charts are often referred directly to statistical process control. “X-bar and R charts”, “X-bar and S charts”, “X and moving R charts”, “np charts”, “p charts”, “u charts”, and “c charts” are the typical single-variable control charts used in industries (Kwok, & Tummalla, 1996).

These charts are called Shewhart control charts. Note that for continuous data, the two types of chart are simultaneously used in the same way as a single control chart.

For continuous data (variables):

- $x - R$ (average and range) chart
- $x - s$ (average and standard deviation) chart
- $x - Rs$ (individual observation and moving range) chart

For discrete data (attributes):

- p (fraction of nonconforming items) chart
- np (number of nonconforming items) chart
- c (number of defects) chart
- u (number of defects per unit) chart (Park, 2003, pg. 77).

Format of control chart is shown at Figure 3.7.

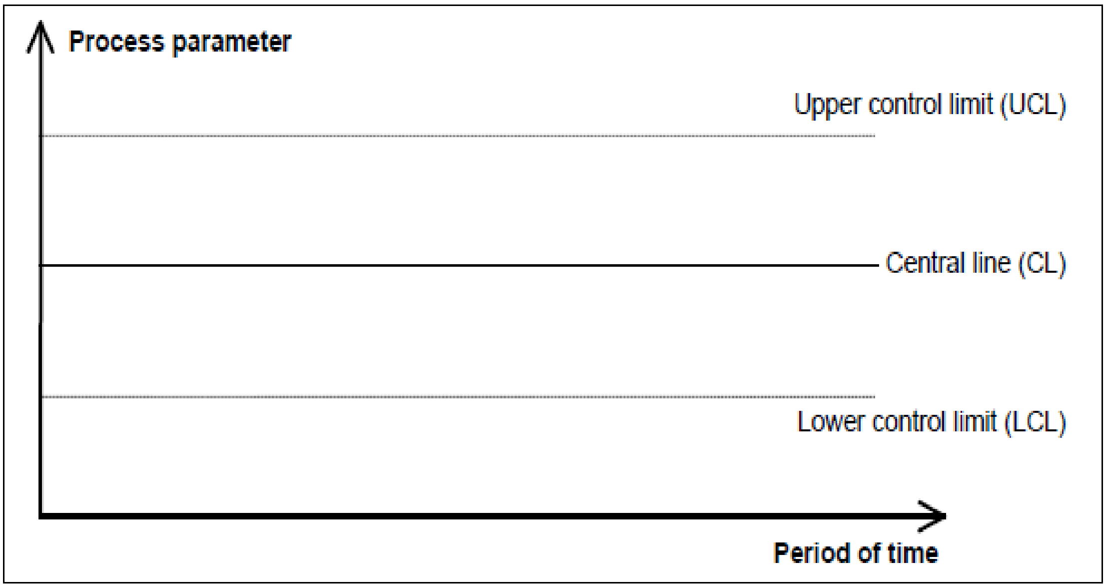


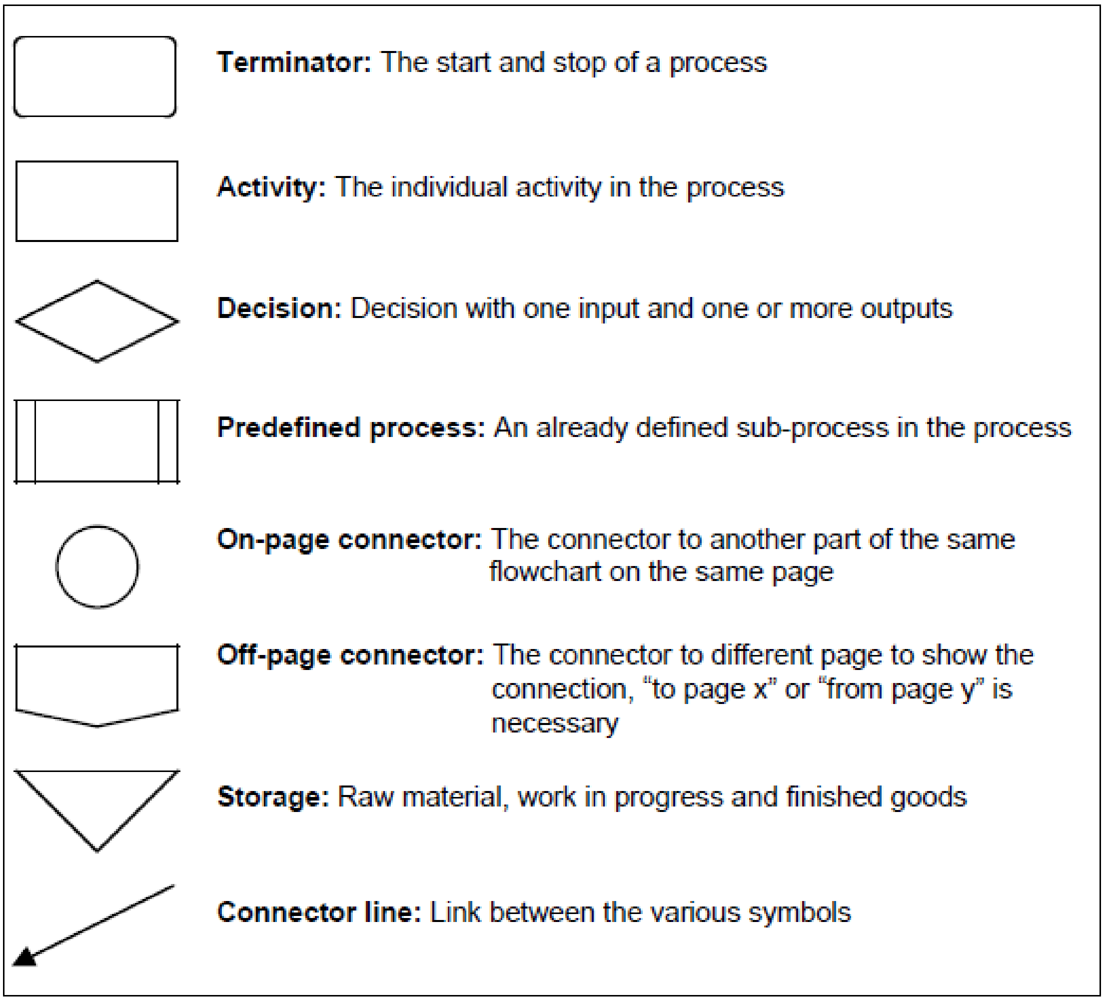
Figure 3.7 An example control chart (McCarty, Daniels, Bremer, & Gupta, 2005, pg. 462)

3.2.7 Flowchart

A flowchart provides a picture of the steps that are needed to understand a process. Flowcharts are widely used in industry and have become a key tool in the development of information systems, quality management systems, and employee handbooks (Park, 2003, pg. 85-86).

A process flow chart is a pictorial representation showing the steps of a process in sequence. It frequently describes the key process activities, their sequence and who is responsible for them. The flow chart has many applications. The principal one is in investigating opportunities for improvement by gaining a better understanding of how the various stages in a process relate to one another (Truscott, 2003, pg. 154). The mostly common used flowchart symbols and their definitions are illustrated in Figure 3.8.

Flowcharts depict certain aspects of processes and they are usually complemented by other types of diagram. For instance, Kaoru Ishikawa defined the flowchart as one of the seven basic tools of quality control, next to the histogram, Pareto chart, check sheet, control chart, cause-and-effect diagram, and the scatter diagram (Flowchart, n.d.).



Terminator: The start and stop of a process

Activity: The individual activity in the process

Decision: Decision with one input and one or more outputs

Predefined process: An already defined sub-process in the process

On-page connector: The connector to another part of the same flowchart on the same page

Off-page connector: The connector to different page to show the connection, "to page x" or "from page y" is necessary

Storage: Raw material, work in progress and finished goods

Connector line: Link between the various symbols

Figure 3.8 The mostly common used flowchart symbols (Park, 2003, pg. 87).

3.2.8 Quality Function Deployment (QFD)

Quality Function Deployment is a structured technique to ensure that customer requirements are built into the design of products and processes. In Six Sigma, QFD is mainly applied in improvement projects on the design of products and processes (Park, 2003, pg. 88).

According to Cohen (1995), QFD as a method for structured product planning and deployment that enables a development team to specify clearly the customer's wants and needs, and then to evaluate each proposed product or service capability systematically in terms of its impact on meeting those needs.

QFD’s objectives are to: identify the customer; determine what the customer wants; and provide a way to meet the customer’s desires (Kathawala, & Motwani, 1994).

There are six steps that can be followed to conduct a QFD analysis: (McCarty & others, 2005, pg. 486-488).

- Step 1: The first step is the articulation of customer requirements. Techniques used could be interviewing, observation, prototyping, conceptual modeling, etc. The data from marketing research are also used. These requirements are also known as the What's".
- Step 2: In the second step, the company's current product is ranked against the competitors.
- Step 3: In the third step, the team looks at Product/Process Characteristics, in other words, the "How's" of meeting the customer requirements. Candidate critical customer requirements (CCR’s) are listed across the top and for each their relevance is considered and ranked as to which will address customer needs.
- Step 4: In the fourth step, the team relates customer and technical requirements with ratings such as "high", "moderate", "low", and "no" correlation. The team evaluates the degree to which customer wants and needs are addressed by the product/process characteristics.
- Step 5: In the fifth step, the roof of the "House" focuses on relationships among product/process characteristics. It shows whether the "Hows" reinforce or conflict with one another.
- Step 6: In the final section of the QFD matrix, the team summarizes the key conclusions. It ranks the relevance of product or process characteristics to the attainment of customers' wants or needs.

The Figure 3.9 shows the format of QFD.

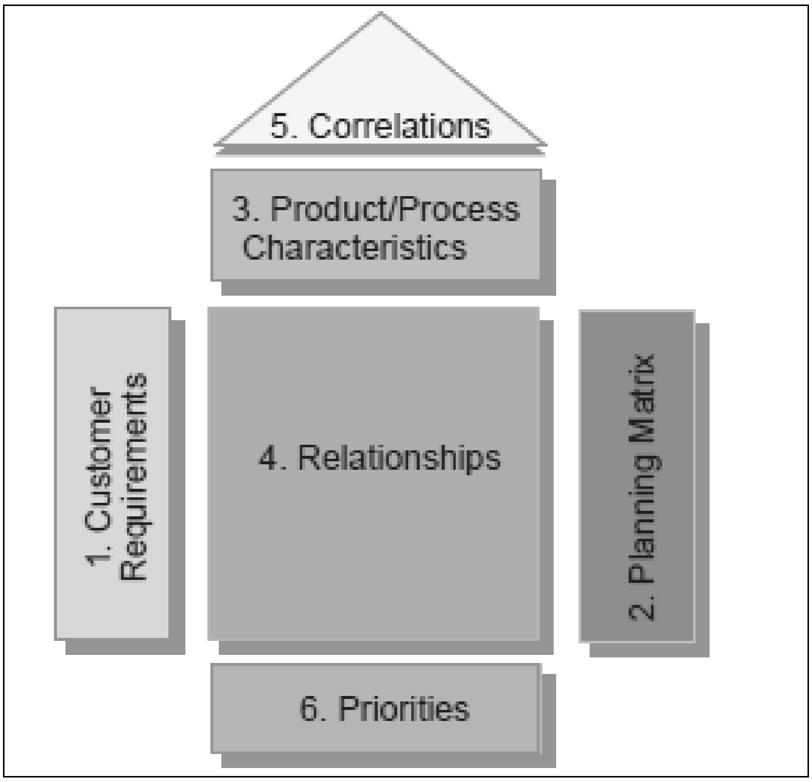


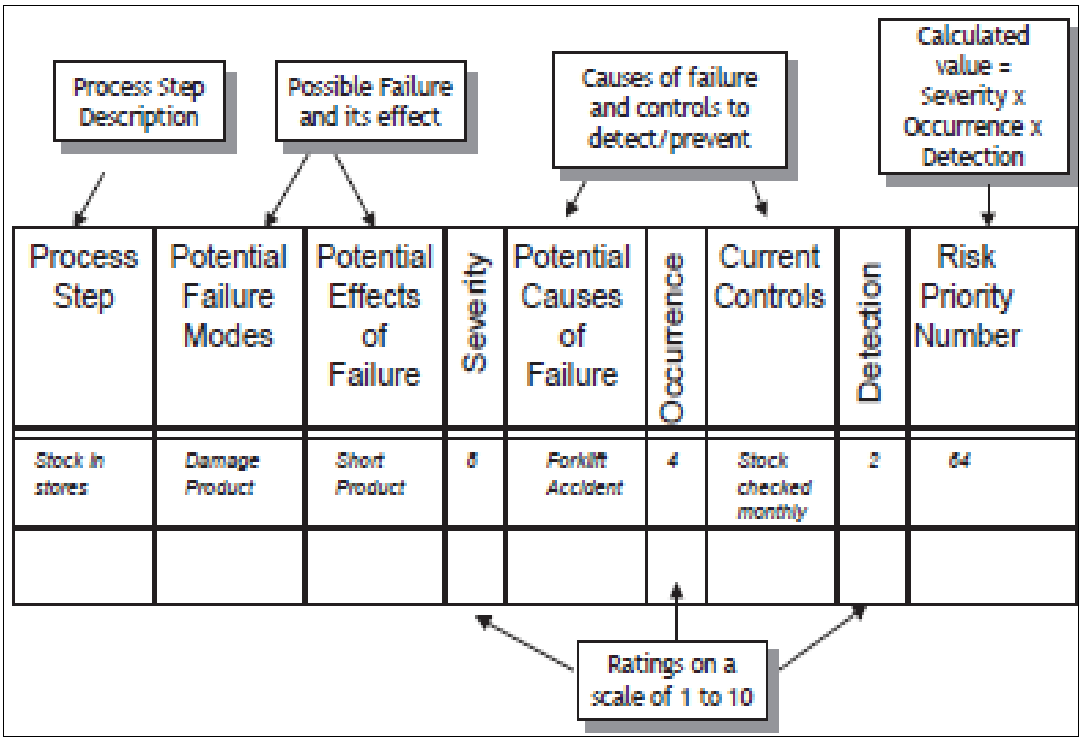
Figure 3.9 QFD format (McCarty & others, 2005, pg. 386).

3.2.9 Failure Mode and Effect Analysis

FMEA was first introduced in the aerospace industry roughly 30 years ago and is now utilized in various industrial areas, for example, in the automotive industry. The method involves the investigation and assessment of all causes and effects of all possible failure modes on a system, that is, a product or a process, in the earliest development phases. The importance of FMEA has raised due to stricter product liability laws and companies' need to seek compliance and to QS (Quality System) 9000 certification (an emerging standard in quality management), in which an appropriate preventive method is prescribed (Leondes, 2002, pg. 1415).

Failure mode and effects analysis provides an effective tool for improving product design and process planning by discovering potential product and process failures so that preventive measures can be taken in early stages (Chang, Liu, & Wei, 2001).

There are two types of FMEA; one is design FMEA and the other is process FMEA. Design FMEA applications mainly include component, subsystem, and main system. Process FMEA applications include assembly machines, work stations, gauges, procurement, training of operators, and tests (Park, 2003, pg. 113). There is example at Figure 3.10.



Process Step	Potential Failure Modes	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurrence	Current Controls	Detection	Risk Priority Number
Stock in stores	*Damage Product*	*Short Product*	*8*	*Forklift Accident*	*4*	*Stock checked monthly*	*2*	*64*

Figure 3.10 A FMEA chart (McCarty & others, 2005, pg. 447).

Benefits of a properly executed FMEA include the following: (Park, 2003, pg. 113)

- Prevention of possible failures and reduced warranty costs
- Improved product functionality and robustness
- Reduced level of day-to-day manufacturing problems
- Improved safety of products and implementation processes
- Reduced business process problems.

The process for conducting an FMEA is straightforward. The basic steps are outlined below to achieve above benefits: (FMEA, n.d.)

- Describe the product/process and its function. An understanding of the product or process under consideration is important to have clearly articulated.
- A block diagram of the product/process should be developed. This diagram shows major components or process steps as blocks connected together by lines that indicate how the components or steps are related.
- Complete the header on the FMEA Form worksheet: Product/System, Subsys./Assy., Component, Design Lead, Prepared By, Date, Revision (letter or number), and Revision Date. Modify these headings as needed.
- Use the diagram prepared to begin listing items or functions. If items are components, list them in a logical manner under their subsystem/assembly based on the block diagram.
- Identify Failure Modes. A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent.
- A failure mode in one component can serve as the cause of a failure mode in another component. Each failure should be listed in technical terms. Failure modes should be listed for functions of each component or process step.
- Describe the effects of those failure modes. For each failure mode identified the engineer should determine what the ultimate effect will be. A failure effect is defined as the result of a failure mode on the function of the product/process as perceived by the customer. Establish a numerical ranking for the severity of the effect. The intent of the ranking is to help the analyst determine whether a failure would be a minor nuisance or a catastrophic occurrence to the customer.
- A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented.
- Enter the Probability factor. A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring). A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable.

- Identify Current Controls (design or process). Current Controls (design or process) are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the Customer.
- Determine the likelihood of Detection. Detection is an assessment of the likelihood that the Current Controls (design and process) will detect the Cause of the Failure Mode or the Failure Mode itself, thus preventing it from reaching the Customer. Based on the Current Controls, consider the likelihood of Detection using the following table for guidance.
- Review Risk Priority Numbers. The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings: RPN = (Severity) x (Probability) x (Detection) The RPN is used to prioritize items than require additional quality planning or action.
- Determine Recommended Action(s) to address potential failures that have a high RPN.
- Assign Responsibility and a Target Completion Date for these actions. This makes responsibility clear-cut and facilitates tracking.
- Indicate Actions Taken. After these actions have been taken, re-assess the severity, probability and detection and review the revised RPN's. Are any further actions required?
- Update the FMEA as the design or process changes, the assessment changes or new information becomes known.

3.2.10 Analysis of Variance

The analysis of variance is a technique that consists of separating the total variation of data set into logical components associated with specific sources of variation in order to compare the mean of several populations (Dodge, 2008, pg. 9).

This analysis also helps us to test certain hypotheses concerning the parameters of the model, or to estimate the components of the variance. The sources of variation are globally summarized in a component called error variance, sometime called within-treatment mean square and another component that is termed “effect” or treatment, sometime called between-treatment mean square (Dodge, 2008, pg. 9).

There are three conceptual classes of such models (Analyze of Variance, 2009):

- The fixed-effects model of analysis of variance applies to situations in which the experimenter applies several treatments to the subjects of the experiment to see if the response variable values change. This allows the experimenter to estimate the ranges of response variable values that the treatment would generate in the population as a whole.
- Random effects models are used when the treatments are not fixed. This occurs when the various treatments (also known as factor levels) are sampled from a larger population. Because the treatments themselves are random variables, some assumptions and the method of contrasting the treatments differ from the fixed-effects model.
- Mixed-effect models describe situations where both fixed and random effects are present.

3.2.11 Design of Experiment

Design of experiments, or experimental design, is the design of all information-gathering exercises where variation is present, whether under the full control of the experimenter or not. Often the experimenter is interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"), which may be people, parts of people, groups of people, etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences (Design of Experiment, n.d.).

The design of experiments plays a major role in many engineering activities. For instance, DOE is used for; (Park, 2003, pg. 104-105)

- Improving the performance of a manufacturing process. The optimal values of process variables can be economically determined by application of DOE.
- The development of new processes. The application of doe methods early in process development can result in reduced development time, reduced variability of target requirements, and enhanced process yields.
- Screening important factors.
- Engineering design activities such as evaluation of material alternations, comparison of basic design configurations, and selection of design parameters so that the product is robust to a wide variety of field conditions.
- Empirical model building to determine the functional relationship between x and y.

For an effective experimental design should be design step by step as follows: (Design of Experiment, n.d.)

- Select problem: In order to design an experiment, a problem has to be selected and phrased. It is the selection and the phrasing of the problem that will direct the design and outcomes of an experiment. The simplest and most concise way of phrasing a problem is by addressing the "Who, What, When, Why and How" questions. In designing the experiment, you need to consider underlying models that have already been proven to make your research more in depth and accurate.
- Determining dependent variables: The dependent variables are the variables that are being measured throughout the experiment. There can be many different dependent variables measured during an experiment. First, you need to split the dependent variables into two different subcategories, system level and individual level. On a system level, questions are taken into consideration regarding the experiment itself taking place. System level variables need to be created to ensure that when the conclusion is reached, it is backed up by as many different

angles as possible to support the conclusion. This idea is known as converging operations.

- Determining independent variables: The independent variables are the variables that are manipulated in the experiment. Independent variables include things related to people such as age, sex, vision, level of education or general work experience. This brings about the topic of obtaining suitable human subjects. To ensure that the specifications of the independent variables are met, subjects should be screened prior to running the experiment. Subjects may be offered an incentive in cash or kind in exchange for their cooperation.
- Determining the number of levels of independent variables: The number of levels of independent variables determines the number of experimental conditions to be manipulated. This is important in determining the extent of the scope of the experiment.
- Determining the possible combinations: The types of combinations between the independent variables have to be established in order for the experiment to be valid Therefore, it is important to establish the possible types of combinations.
- Determining the number of observations: It is insufficient to obtain one observation. Depending on the desired analysis, there are certain factors that need to be taken into consideration when deciding on the number of observations. This includes the number of trials before a subject becomes familiar with the experiment, the number of trials before fatigue sets in and the number of trials required obtaining statically significant data.
- Redesign: is necessary in order to obtain the optimal design. When flaws or inconsistencies are found in the current experiment design, a redesign is necessary to correct them.
- Randomization: A randomized, controlled trial is considered the most reliable and impartial method of determining necessary data. Randomization is a process that assigns research participants by chance,

rather than by choice, to either the investigation group or the control group.

- Meet ethical and legal requirements: Legal requirements have accordingly developed.
- Mathematical model: In order to ensure that the experiment is valid, it is useful to develop a mathematical model to the entire system. By doing this, anomalies and infeasible ideas can be weeded out immediately. By basing the experiment upon valid mathematical principles, it ensures that all aspects of the experiment are practical and feasible.
- Data collection: The data collection portion of experiment design must make sure that the experiment is supported by factual data. This involves collecting raw data while adhering to the experimental conditions. The data from this portion is expected to be large and chunky.
- Data reduction: This portion involves cleaning up the raw data into manageable chunks which can then be utilized. Not all the data that was collected may be pertinent and thus should be excluded from the analysis.
- Data verification: The most important part of the entire process is the data verification. This is often done by plotting the reduced data, allowing the experimenter to visually locate significant outlying points which may indicate erroneous data collection. If the data is skewed in any way, experimenters either look back at the methods used or redesign a phase of the experiment or they faithfully cite their findings.

3.2.12 Process Capability

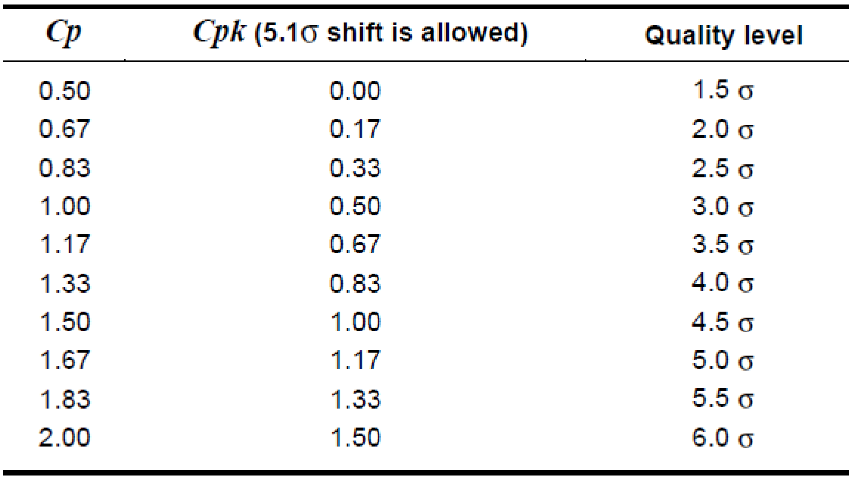
Process capability is the ability of the process to meet the requirements set for that process. One way to determine process capability is to calculate capability indices. Capability indices are used for continuous data and are unit less statistics or metrics. There are many capability indices but the two most commonly used are Cp and Cpk (or Pp and Ppk) (McCarty & others, 2005, pg. 384).

The formula for Cp is:

$$Cp = \frac{\text{Upper Sigma Level (USL)} - \text{Lower Sigma Level (LSL)}}{6\sigma}$$

Cp is the potential capability indicating how well a process could be if it were centered on target. This is not necessarily its actual performance because it does not consider the location of the process, only the spread. It doesn't take into account the closeness of the estimated process mean to the specification limits (McCarty & others, 2005, pg. 384). Relation between Cp, Cpk and Sigma level is illustrated at Table 3.2.

Table 3.2 Cp, Cpk and sigma level index (Park, 2003, pg. 23)



Cp	*Cpk* (5.1σ shift is allowed)	Quality level
0.50	0.00	1.5 σ
0.67	0.17	2.0 σ
0.83	0.33	2.5 σ
1.00	0.50	3.0 σ
1.17	0.67	3.5 σ
1.33	0.83	4.0 σ
1.50	1.00	4.5 σ
1.67	1.17	5.0 σ
1.83	1.33	5.5 σ
2.00	1.50	6.0 σ

3.2.13 Sigma Level

Sigma Level is typically used with discrete data such as Pass/Fail data. Sigma Level is based on a calculation of defects per million opportunities. The million in the calculation is a scaling factor. An opportunity is defined as a chance for a defect to occur per unit or delivery of service. An opportunity is a chance for a failure to meet customer requirements to occur per unit or delivery of service. In many cases, the number of opportunities should be defined to be one - the customer receives it right (no defects - therefore, no failure) or the customer doesn't receive it right (any number of defects - therefore, a failure). However, in processes where there is a need to differentiate between complexities in product, the team may define more opportunities (McCarty & others, 2005, pg. 382).

In order to calculate the DPMO, three distinct pieces of information are required:

- Total number of units produced
- Total number of units defect
- The number of defects opportunities per unit

The formula is :

DPMO= (Number of units defect X 1.000.000)

((Number of Defect Opportunities/Unit) X Number of Units)

After DPMO is found, conversion of DPMO to Sigma Level can be calculated by the following formula:

$$\text{Sigma Level} = 0.8406 + \sqrt{(29.37 - 2.221 \times \ln(\text{DPMO}))}$$

Results are showed in a Sigma Level table. An example of sigma level table is illustrated in Table 3.3.

Table 3.3 An example of sigma level table

Sigma Level	Percentage Yield	Defect Per Million
1 σ	% 31	691462
2 σ	% 69	308538
3 σ	% 93.3	66807
4 σ	% 99.38	6210
5 σ	% 99.977	233
6 σ	%99.99966	3.4

CHAPTER FOUR
A SIX SIGMA APPLICATION IN A CONSTRUCTION SECTOR

4.1 The Aim of Application

Although, Six Sigma's DMAIC methodology was created for improving manufacturing sector processes, it is also used in service and construction sectors etc. Because, Six Sigma is a business strategy and DMAIC have been applied to increase profit, efficiency, customer satisfaction etc. and to decrease failure rate.

Construction sector companies have got similar purposes like manufacturing sector companies. But construction sector processes are not uniform like the processes of other sectors. Therefore, improving, fixing, preventing or correcting processes may become difficult. But it is not impossible to apply Six Sigma and DMAIC methodology in construction sector.

The aim of this chapter is to present an example about Six Sigma applications in construction processes. Additionally, this chapter shows us how Six Sigma applications can be adopted, enabled and applied to the construction companies.

4.2 The Company

Güriş Construction and Engineering Co, Inc., which was established as a collective company in year 1958, has succeeded in being one of the leading contracting firms of Turkey since its establishment up to this day. Güriş has carried out business activities in Turkey, Middle East, Near and Central Asia, Commonwealth of Independent States and North African countries and has realized turnkey projects in a very wide range, namely in almost every field of the construction sector. Güriş, which has around 20 shareholders and more than 5000 employee, took the name " Güriş " on 27th August 1973 and reached today continuing its development.

Pride of Güriş is that it is one of the most long-established construction firms in Turkey with its past of almost half a century, and it has succeeded in identifying its name with quality and trust before all its employers within this period of time.

Güriş has made contribution to realization of important works in every category of hydraulic structures varying from dams to treatment plants.

Güriş has increased its interest in the field of energy projects as of mid-1970s. Güriş, which gained its first experience in the energy sector with Thermal Power Plants, enriched this experience with Hydro-electrical Power Plants. Güriş, adding Wind and Geothermal Power Plant projects, which it kept in its agenda, to its portfolio, makes effort to offer excellent service in the field of today's modern energy projects.

Güriş, from the date of its establishment till today, not only developed its own construction methods, but also makes great effort to obtain the most advanced technology that can be owned, in technical cooperation with world's leading firms in its field and makes investments for this purpose. Güriş is one of the remarkable construction firms in Turkey that is capable of constructing such energy projects on Turkey basis.

Güriş not only uses all opportunities of technology with the aim of rendering safe, efficient and attractive places such as houses, hospitals, hotels, theaters, banks, office buildings and business centers, which give opportunity to realization of various activities of daily life, starting with solutions it brought to the problem of sheltering that is one of the most fundamental needs of human, but it also creates works in harmony with its environment, considering also esthetic concerns, and it continues its activities in this direction.

4.3 Application of DMAIC Methodology

In this section, DMAIC methodology is used in order of Define, Measure, Analyze, Improve and Control to solve problems in construction processes.

4.3.1 Define Phase

The project was started with the Define Phase according to the DMAIC methodology. Firstly, description of construction project was explained. Then, Six Sigma project and project team was selected and problem was defined at this phase.

4.3.1.1 Description of construction project

Güriş implements the 45 MW Germencik Geothermal Power Plant Project to construct the geothermal power plant. Geothermal Plant will produce energy by gathering geothermal brine (underwater) and steam mixture to the earth. For producing energy, brine and steam mixture will be hoisted from drilled wells, then mixture will be separated and steam will circulate the turbine. Finally, brine will be injected back to the injection wells. Plant Construction Area is illustrated at Figure 4.1.

This project, is the composed of drilling, civil, electrical and mechanical engineering processes. These processes are also composed of sub-processes.

Project began with 9 drilling operations additional to 5 production wells at the geothermal area. This area locates on the west side of Ömerbeyli and on the west of Big Menderes Graben. The aim is to drill production and reinjection wells for steam and brine. Totally 9 wells (4 productions and 5 re-injections) were drilled between the depts of 1500 meters to 2000 meters.

After drilling process, civil engineering process goes through the period which includes preparing infrastructure area, superstructure, rough and delicate construction and landscaping of the plant.

Laying groundwork for plant construction area is performed under preparing infrastructure area. Superstructure constructions include the construction of roads, sewers etc. Rough constructions include the rough construction of warehouse, administration building, turbine building, and guest houses. Delicate constructions include the delicates of rough construction and landscaping includes the arranging of plant area after all constructions are finished.

Figure 4.1 A scope of plant construction area

Mechanical process is composed of steel structure assembly, pipe assembly, sandblasting of steel structure and pipes, painting, supporting, insulating, finalizing bolted assembly by torque and mounting of turbine, generator, pumps and tanks. Steel structure assembly includes the installation of steelworks for pipe and equipment assembly. At pipe assembly, pipelines are assembled to transfer steam and water to the plant system. At sandblasting, pipes and steel structures are cleaned up from corrosion. Metals are protected against corrosion by help of painting works.

Pipelines and equipments are fixed and carried by help of supporting. System heat dissipation is obstructed by insulating pipelines and equipments. At torching, bolting of equipments is done and at equipment assembly, equipments like turbine, generator, miscellaneous pumps and tanks are assembled.

On the other hand, electrical process includes cable assembly, instrumentation, lightning protection, lighting, finalizing commissioning of the plant systems by energizing of all equipments and systems. Cable assembly includes all the cabling of equipments and systems. Measurement systems are set at instrumentation. Plant protection against lightning is done by assembly of protection equipment. Lamppost assemblies are done at lighting of plant. Finally, commissioning & energizing of plant and equipments are done at commissioning and energizing processes. Figure 4.2 shows the tree diagram of project's processes.

4.3.1.2 Selection of project and project team

For plant, welding is very important stage of mechanical engineering process. Because, the brine and steam are gathered from production wells, supplied to plant and injected to reinjection wells by pipelines and pipelines water- resistance should be achieved in the long term.

Unless pipes were welded, pipelines had not been assembled. For this reason, assembly operations continued and/or waited the welding of pipes. Additionally, current and possible welding failures were shift project schedule and cause extra waste of time. Therefore, the welding of pipes has been pointed as bottleneck.

Non-destructive tests (visual, radiographic, penetrate and magnetic) have been done to the welded pipes. When welding was not proper according to QA/QC (Quality Assurance/Quality Control), installation procedures and international standards, welded pipes became non-conformity. Because of non-conformance welding, welded pipes were repaired or re-welded and this was caused to loss of money and time.

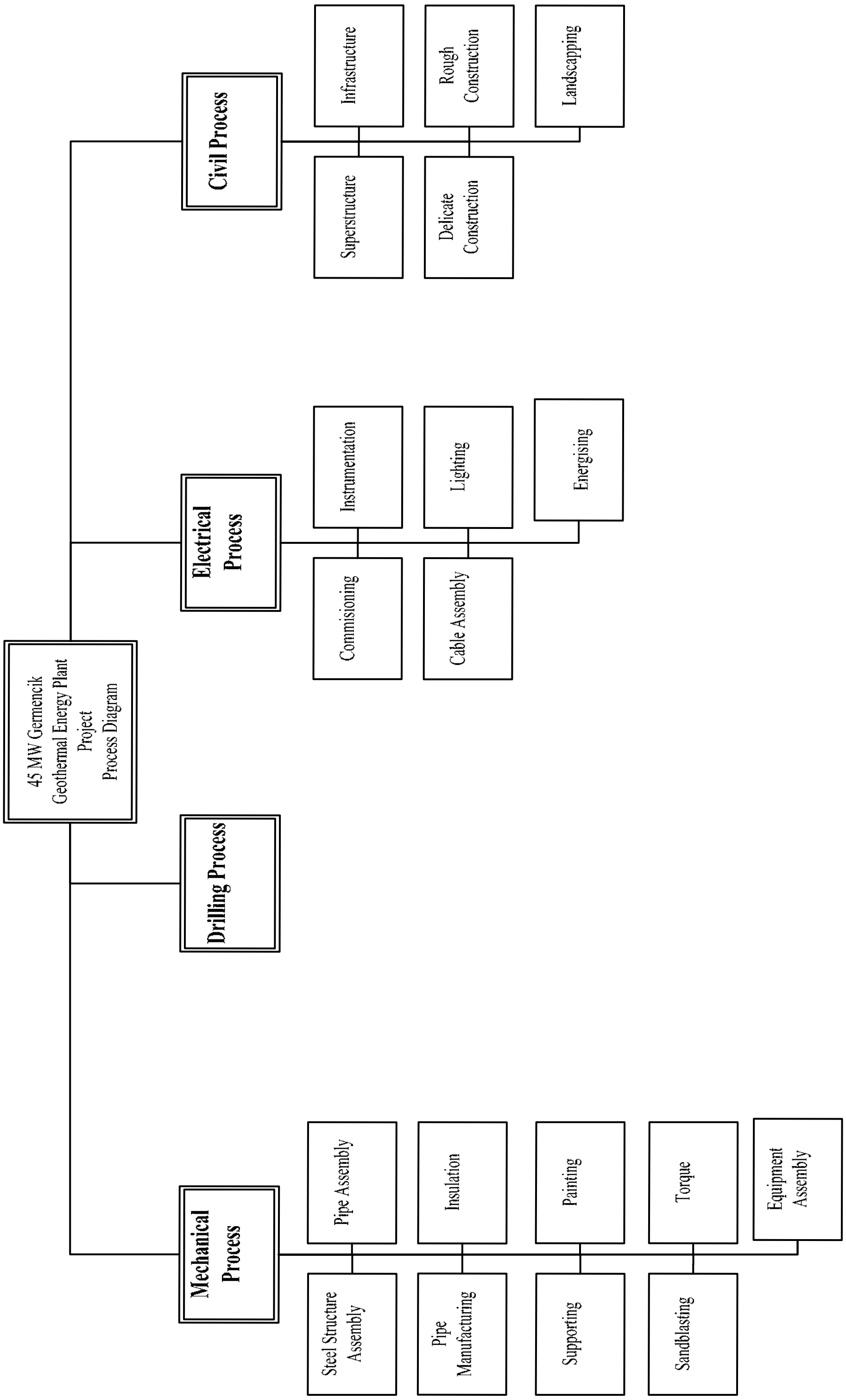


Figure 4.2 Tree diagram of project's process

As a result of all these processes, Germencik Geothermal Power Plant Project stated the project's CTQ as "To prevent loss of time, error rate must be reduced".

Then, project execution team was created to apply Six Sigma methodology for welding process improvement. For this reason, 1 site manager, 1 QA/QC Engineer, 1 QA/QC foreman, 1 welding foreman, 1 mechanical department chief and 1 mechanical foreman were chosen as member of project team.

4.3.1.3 Definition of problem

After CTQs and project team members were determined, project team started with mapping the welding process.

First of all, welding processes are started with pre-welding stages. At pre-welding stage, weld mouths are prepared in the pipe preparation station. Then, pipes are connected by method of centering if mouths are conformance according to standards. Otherwise, mouths are repaired before centering. Later than mouths are confirmed; pipes are transported to the welding station with forklifts and put up to welding bench. Lastly, welding equipments are prepared by welder assistant for welding main stages.

After all of the pre-welding processes, welding process proceed with main stage. Firstly, protection gas is given inside of pipes to protect material against oxidation. After, root pass is welded by welder and Visual Test (VT)[1] is applied to check root pass.

If root pass is appropriate according to the standards and gets conformance result from VT, hot pass is welded to increase penetration of root pass. VT is also applied to confirm the hot pass.

Lastly, hold passes and cap passes are welded. After all passes get conformance result from VT, welded pipe is transported to assembly area for installing to the pipeline. Figure 4.3 shows the weld passes at a weld and Figure 4.4 defines process diagram of current welding process which was mapped by project team.

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[1] See Appendix A For VT Report Format

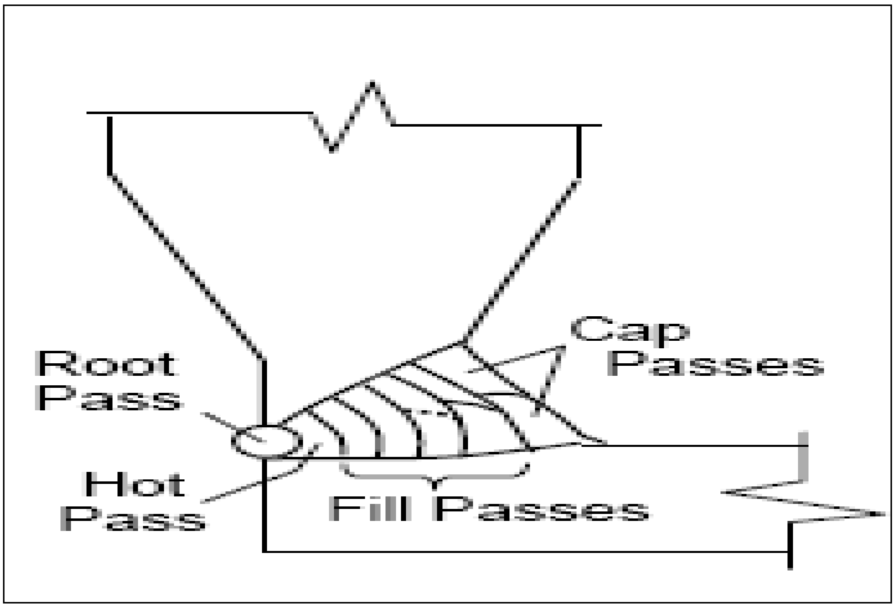


Figure 4.3 The drawing of weld passes

After welding process was mapped, project team defined causes of welding problems by using method of brainstorming. Then, project team used cause and effect diagram to classify reasons and to find the roots of problem.

Causes were classified under four categories which are Management, Material, Man and Medium. Then, Primary and secondary causes were identified by using method of brainstorming.

Pass Failures and Disability are determined as primary level causes at category of Man. Procedure and Project Failures are determined as primary level causes at category of Management. Weather Temperature, Rain, Humidity and Wind are determined as primary level causes at category of Medium. And lastly, Electrode and Pipe Failures are determined as primary level causes at category of Material.

After primary level causes were determined, secondary level causes were identified at some primary level causes. Therefore, Root Pass Failures, Hot Pass Failures, Cap Pass Failures and Hold Pass Failures were determined as secondary level causes of Pass Failures. Figure 4.5 shows Cause and Effect Diagram of welding Process problems.

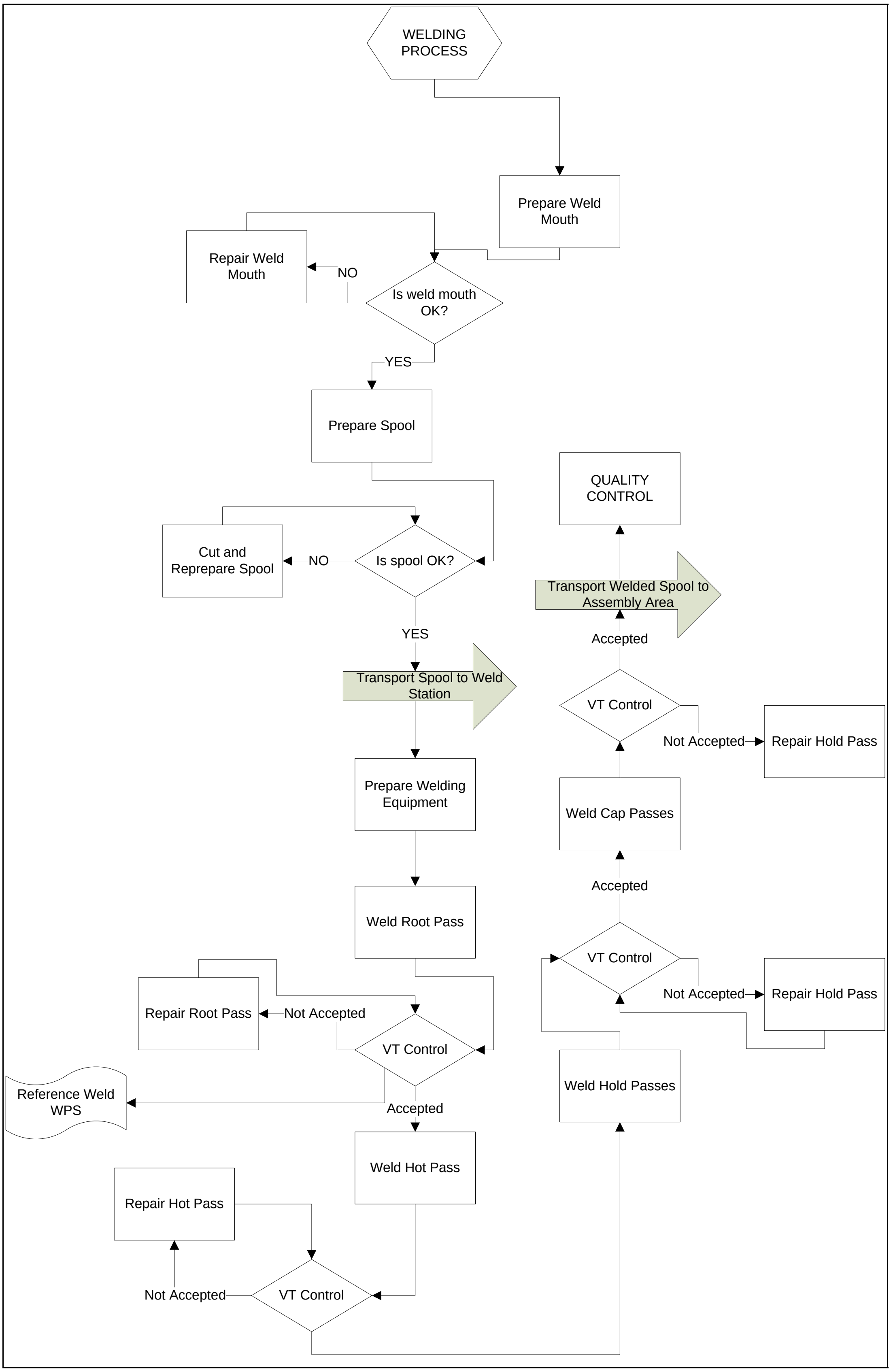


Figure 4.4 Flowchart of welding processes

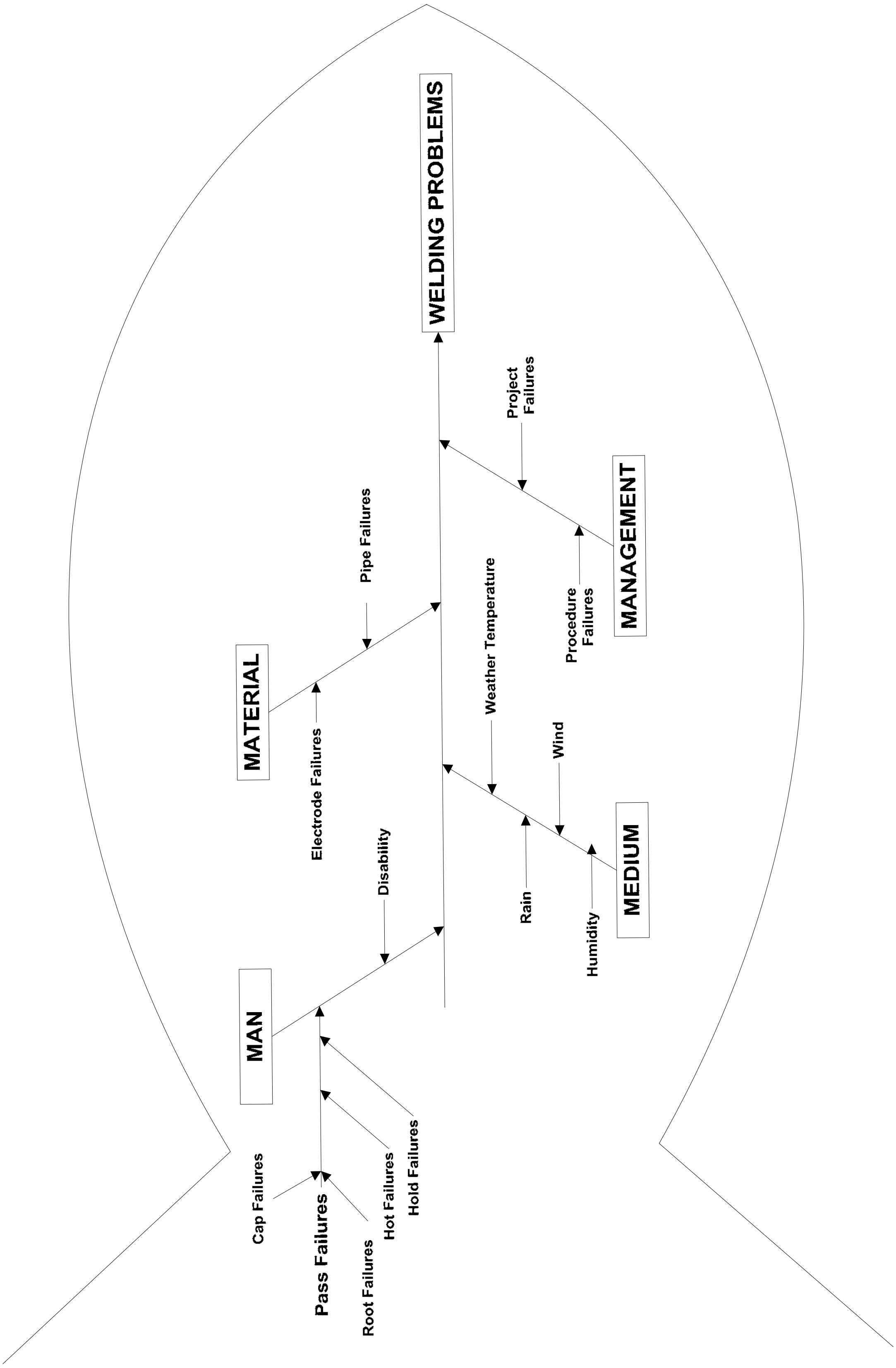


Figure 4.5 Ishikawa diagram of welding problems

After causes had been established and classified by using Cause and Effect Diagram, application continued by calculating grade of causes. Management team graded these causes from 1 to 10 one by one. In grading, 1 point means “no effect to the product” and 10 point is used for the most important causes. Importance Grading Table is illustrated in Table 4.1. In order to calculate the importance for each reason, the average grades were calculated through the grades coming from team members.

Then, reasons were graded according to occurring probability of frequency between 1 and 10. 1 point is given for the most improbable causes and 10 point is given for the very high probability that the failure appears. Previous experiences and comments were used during grading. Frequency Grading Table is illustrated in Table 4.1.

Table 4.1 Importance and frequency criteria of Ishikawa diagram grading table

CRITERIA FOR IMPORTANCE		Rating
No effect to the product		1 - 2
Insignificant effect to the product, still intact function		3-4
Very low risk of the function in the production		5-6
Problem with the function in the production		7-8
Serious Problem with the function in the production		9-10
CRITERIA FOR PROBABILITY OF FREQUENCY	Frequency	Rating
It is most improbable that the defect appears.	< 1 / 100 000	1
Very low probability that the defect appears, similar construction without defect	< 1 / 10 000	2-3
Low probability that the defect appears	< 1 / 1 000	4-5
Certain probability that the defect appears	< 1 / 100	6-7
High probability that the defect appears	< 1 / 10	8-9
Very high probability that the defect appears	< 1 / 1	10

Then, importance grade of a cause was multiplied with frequency grade of same cause in order to find root causes. This multiplication was applied for each cause. As a result of multiplication, root pass failures, hot pass failures, cap pass failures and electrode failures were appeared with higher results than others. And they were determined as main roots of welding problems by project team. Grading Table of Ishikawa Diagram is illustrated in Table 4.2.

Table 4.2 Ishikawa diagram grading table

REASONS	**Importance**	**Frequency**	**TOTAL**
MANAGEMENT			
Project Failures	4	1	4
Procedure Failures	3	1	3
MATERIAL			
Electrode Failures	6	5	30
Pipe Failures	6	2	12
MEDIUM			
Humidity			0
Weather Temperature	3	1	3
Wind	4	1	4
Rain			0
MAN			
Pass Failures			
Hot Pass Failures	7	5	35
Root Pass Failures	9	6	54
Cap Pass Failures	7	4	28
Hold Pass Failures	7	5	35
Disability	5	4	20

As a conclusion, problem was defined clearly and the root causes were determined in definition phase. At the next step, measurements and data collections has been done about root causes.

4.3.2 Measure Phase

At define phase, process and problem were defined and problem's root causes were determined. Aim of the measure phase is to collect data about problem and to measure process and its failures according to define phase. Measurements were started with collecting data about the current situation of welding process. For this purpose, daily total welding quantities and daily total welding failures have been collected for a month. The daily welding records are illustrated in Table 4.3.

Table 4.3 Total welding records

TOTAL WELDING RECORDS					
Date	**Total Welding Production Quantity**	**Welding Failure Quantity**	**Date**	**Total Welding Production Quantity**	**Welding Failure Quantity**
06.10.2008	*71*	*8*	21.10.2008	*101*	*5*
07.10.2008	*86*	*7*	22.10.2008	*54*	*1*
08.10.2008	*68*	*4*	23.10.2008	*25*	*4*
09.10.2008	*58*	*5*	24.10.2008	*45*	*2*
10.10.2008	*135*	*7*	25.10.2008	*19*	*0*
11.10.2008	*60*	*1*	26.10.2008	*10*	*1*
12.10.2008	*87*	*3*	27.10.2008	*14*	*3*
13.10.2008	*45*	*4*	28.10.2008	*22*	*3*
14.10.2008	*44*	*4*	29.10.2008	*44*	*6*
15.10.2008	*54*	*5*	30.10.2008	*11*	*1*
16.10.2008	*78*	*7*	31.10.2008	*62*	*4*
17.10.2008	*133*	*5*	01.11.2008	*53*	*4*
18.10.2008	*103*	*6*	02.11.2008	*17*	*1*
19.10.2008	*84*	*2*	03.11.2008	*35*	*7*
20.10.2008	*76*	*4*	04.11.2008	*9*	*1*

When the total welding failures were collecting, welding failures were classified according to root causes which were determined at define phase. Therefore, failures were recorded with name of "root pass failure", "hot pass failure", "cap pass failure" and "electrode failure". If failures were different than root causes, they were recorded with name of “other failure”. A check sheet which was illustrated in Table 4.4 was prepared to show these failures and types.

Table 4.4 Check sheet of defect items

		DEFECT ITEMS				
		Root Pass Defects	Hot Pass Defects	Electrode Defects	Cap Pass Defects	Others
DATE	06.10.2008	///	/	//	//	--
	07.10.2008	//	//	--	//	/
	08.10.2008	--	--	//	//	--
	09.10.2008	--	//	/	/	/
	10.10.2008	///	/	--	//	/
	11.10.2008	--	--	/	--	--
	12.10.2008	//	--	/	--	--
	13.10.2008	/	//	--	/	--
	14.10.2008	--	////	--	--	--
	15.10.2008	///	--	/	--	/
	16.10.2008	/	//	///	/	--
	17.10.2008	//	--	/	//	--
	18.10.2008	////	//	--	--	--
	19.10.2008	--	/	/	--	--
	20.10.2008	--	///	--	/	--
	21.10.2008	/	//	/	--	/
	22.10.2008	--	--	--	--	/
	23.10.2008	//	/	--	/	--
	24.10.2008	/	--	/	--	--
	25.10.2008	--	--	--	--	--
	26.10.2008	--	--	/	--	--
	27.10.2008	//	/	--	--	--
	28.10.2008	/	--	--	/	/
	29.10.2008	//		///	/	--
	30.10.2008	--	--	--	/	--
	31.10.2008	//	/	--	--	/
	01.11.2008	//	--	/	/	--
	02.11.2008	--		/	--	--
	03.11.2008	///	//	/	/	--
	04.11.2008	--	--	--	--	/
TOTAL		37	27	22	20	9

4.3.3 Analyze Phase

After data had been collected, necessary analysis were implemented to determine the reasons of problems.

Firstly, the variation of welding was analyzed by using time-welding production graph, in order to consider the current situation of welding process. Daily welding quantities were unsteady as can be seen in Figure 4.6. And it meant that daily welding quantity was not stable and it was affected by some problems.

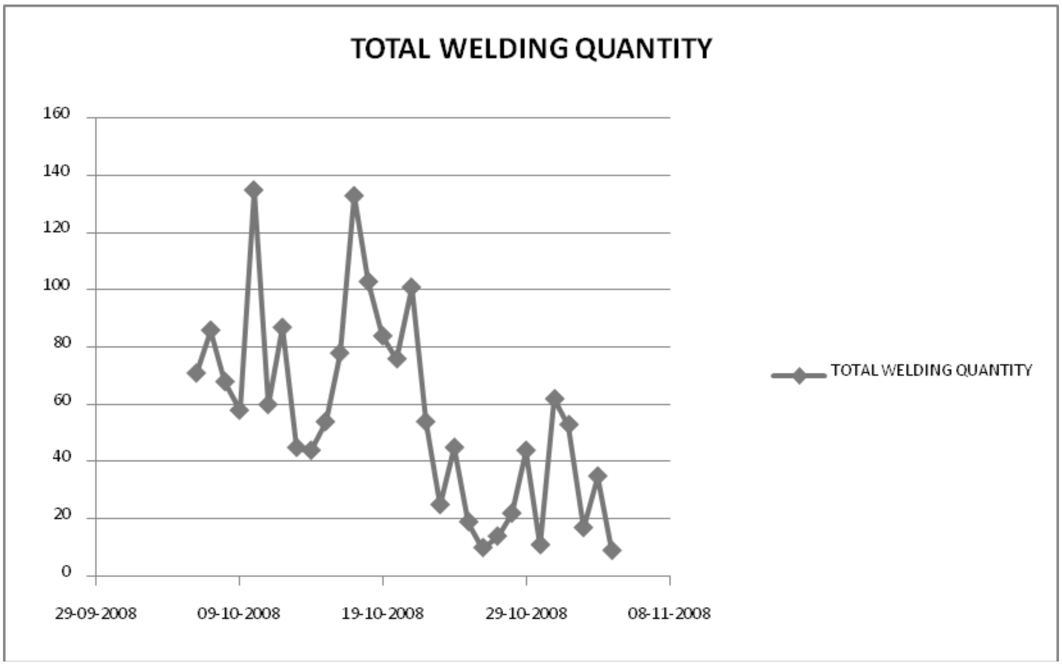
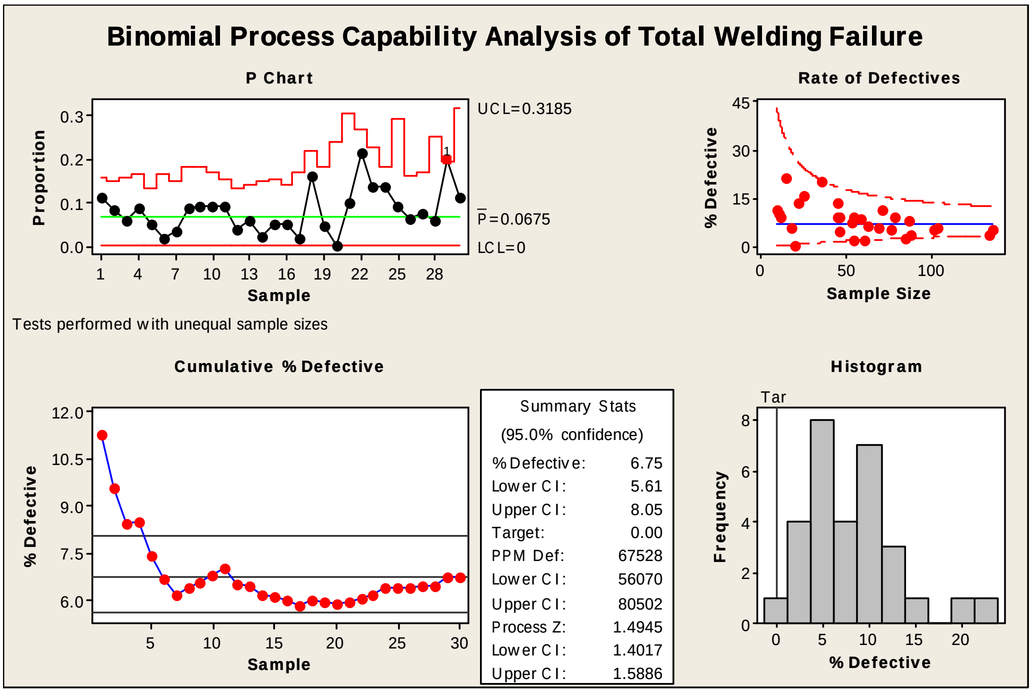


Figure 4.6 Time-welding production graph

Afterward, binomial process capability analysis was used to analyze process capability of welding failures. Because, the binomial distributions are usually used to describe an item passes or fails at inspection.

The p control chart indicated that there was one point out of control limits. This situation verified that the process was not in a state of control. The rate of defectives chart occurred that there was no correlation between defective percent and sample size. The cumulative % defective chart illustrated that the estimate of overall defective rate occurs 6.75 %. And lastly, histogram diagram illustrated that frequency of failure percent occurs around 5-10 % per day. The p control chart, the rate of defectives chart, the cumulative % chart and histogram were illustrated in Figure 4.7. These charts were used to identify process capability, to analyze reality of collected data and to illustrate the rate of failures.



Summary Stats

(95.0% confidence)

%Defective:	6.75
Lower CI:	5.61
Upper CI:	8.05
Target:	0.00
PPM Def:	67528
Lower CI:	56070
Upper CI:	80502
Process Z:	1.4945
Lower CI:	1.4017
Upper CI:	1.5886

Figure 4.7 Process capability analysis of total welding failures before improvement

After, welding production and failures were analyzed; root causes of welding problem have been examined daily for a month. The root causes of welding problem had been determined at define phase.

Root pass failures, hot pass failures, cap pass failures and electrode failures were analyzed 92.2 % parts of welding failures according to Pareto Chart. Figure 4.8 is illustrated Pareto Chart for welding failures.

Lastly, sigma level of process was calculated at the end of this phase to analyze current situation of process. Therefore, defect percent (DP), and defect-per-million-opportunities were calculated to learn the sigma level.

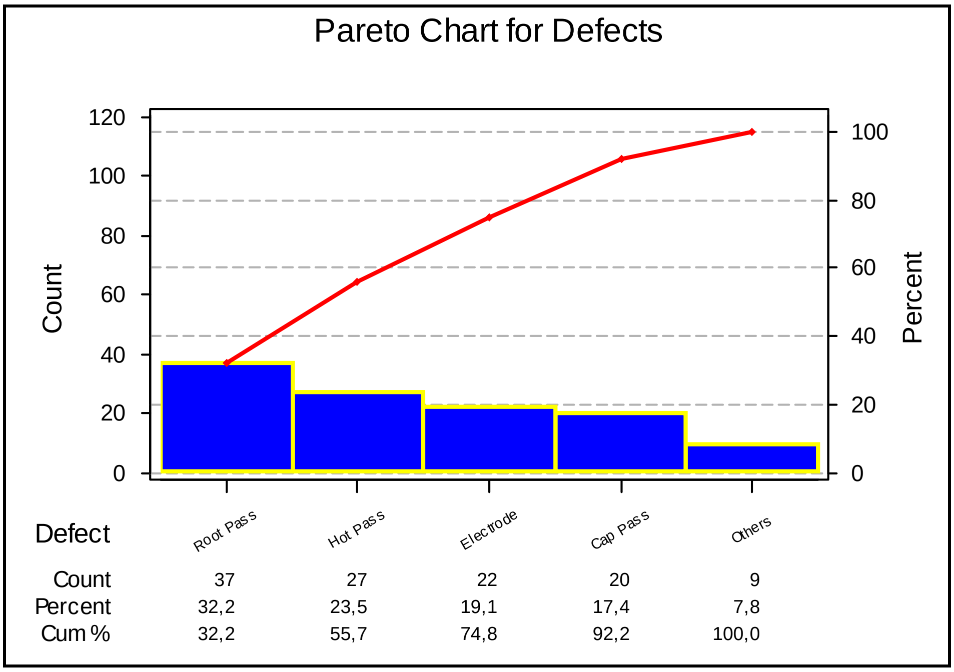


Figure 4.8 Pareto chart for failure items of welding

Total welding quantity had been measured 1703 units and 115 of 1703 units had been confirmed as failure units at Measure Phase. By using these data, DPMO was calculated:

DPMO = (Number of Defect Opportunities per Unit) X 1000000

DPMO = (115/1703) X 1000000

DPMO = 67527.8.

And finally, sigma level was found as 3.00 from detailed conversion of DPMO to sigma quality level with following method:

Sigma Level= $0.8406 + \sqrt{(29.37 - 2.221x \ln(DPMO))}$

Sigma Level= $0.8406 + \sqrt{(29.37 - 2.221x \ln(67527.8))}$

Sigma Level= 3.00 σ

Table 4.5 is illustrated the Sigma Level Chart of process before improvements.

Table 4.5 Sigma level of process

No	STAGE	CODE	VALUE
1	Total Welding Number	*N*	1703
2	Defective Welding Number	*D*	115
3	Defect Percent	*DP*	0.06752
4	The number of independent opportunities for non-conformance per unit	*m*	1
5	Defect Per Million Opportunities	*DPMO*	67527.8
6[2]	Sigma Level	σ	3.00

4.3.4 Improve Phase

Root pass failure, hot pass failure, cap pass failure and electrode failures had been determined as the root causes of welding process at define phase. And then, they had been stated 92.2 % parts of welding failures with measurements and analysis at measure and analyze phases. Afterward, team was decided to recommend improvements to decrease these failures at improve phase.

4.3.4.1 Design of experiment

Firstly, project team decided to implement design of experiment. For this purpose; welder experience, welded pipe wall thickness and used electrode diameter determined as main factors by taking into consideration and deriving benefit from previous experiences and comments about previous problems. Furthermore, project team decided to apply 5 observations for each interaction.

Welders have an effect to welding processes. Therefore, welders were determined as main factors and classified to “rookie” and “star” levels according to their experiences and talents. In addition, rookie and star levels of welders are decided by periodic welder qualification tests.

Wall thickness of welded pipes has an effect to the welding processes, like the

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[2] Sigma levels are shown at the Sigma Level Convert Table which illustrated at Appendix B

effect of welder experience. Because, welded area change by wall thickness of welded pipes. Therefore to welded pipe wall thickness was determined as second main factor and classified to “5.49 mm”, “8.18 mm” and “9.53 mm” levels according to standards of procedures.

Finally, diameter of used electrode was determined as main factor. Because, it is used for filling welds and diameter of used electrode changes according to pass of welding, wall thickness of welded pipe etc. Therefore, it was classified to “3.25 mm” and “4.00 mm” levels according to procedures.

Due to main factors have different levels, team decided to apply general factorial design.

4.3.4.2 Application of experiment

Firstly, “Rookie” and “Star” welders were selected. Then, each welder (“Star” welder and “Rookie” welder) welded 3 types of pipes (Each type of pipe means pipe with a level of wall thickness). Welders used 2 types of electrode (Diameters with 3.25 mm & 4.00 mm.) at welding of pipes. As a conclusion, both of the welders welded each type of the pipes with both type of the electrodes. Each interaction of main factor and levels was implemented 5 times.

Totally, 2 (Levels of Welder) X 3 (Levels of Wall Thickness) X 2 (Levels of Electrode Diameter) X 5 (Times of Each Interaction) = 60 observations were applied randomly. Minitab was used to randomize application of observations. Randomized observation results are shown in Table 4.6.

Total number of failures (Total of root pass failure, hot pass failure, cap pass failure and electrode failures) were recorded at interacted observations and these are shown in Table 4.7.

Table 4.6 Randomized Applied observation results for general factorial design

StdOrder	RunOrder	Welder	Wall Thickness	Electrode Diameter	Observations
42	1	Rookie	5.49	4	1
44	2	Star	9.53	4	1
20	3	Star	9.53	4	1
46	4	Star	8.18	4	2
49	5	Rookie	9.53	3.25	2
17	6	Rookie	5.49	3.25	0
14	7	Rookie	9.53	4	1
48	8	Star	5.49	4	1
3	9	Rookie	8.18	3.25	2
30	10	Rookie	5.49	4	1
59	11	Star	5.49	3.25	0
5	12	Rookie	5.49	3.25	0
33	13	Star	8.18	3.25	1
55	14	Star	9.53	3.25	2
43	15	Star	9.53	3.25	2
37	16	Rookie	9.53	3.25	2
58	17	Star	8.18	4	1
25	18	Rookie	9.53	3.25	1
34	19	Star	8.18	4	1
1	20	Rookie	9.53	3.25	2
2	21	Rookie	9.53	4	1
47	22	Star	5.49	3.25	0
40	23	Rookie	8.18	4	1
11	24	Star	5.49	3.25	1
10	25	Star	8.18	4	1
18	26	Rookie	5.49	4	1
26	27	Rookie	9.53	4	1
32	28	Star	9.53	4	1
53	29	Rookie	5.49	3.25	0
4	30	Rookie	8.18	4	1
38	31	Rookie	9.53	4	1
6	32	Rookie	5.49	4	1
24	33	Star	5.49	4	1
39	34	Rookie	8.18	3.25	2
35	35	Star	5.49	3.25	0
8	36	Star	9.53	4	1
16	37	Rookie	8.18	4	1
19	38	Star	9.53	3.25	2
51	39	Rookie	8.18	3.25	2
9	40	Star	8.18	3.25	1

StdOrder	RunOrder	Welder	Wall Thickness	Electrode Diameter	Observations
45	41	Star	8.18	3.25	1
28	42	Rookie	8.18	4	1
54	43	Rookie	5.49	4	1
27	44	Rookie	8.18	3.25	2
31	45	Star	9.53	3.25	2
15	46	Rookie	8.18	3.25	2
41	47	Rookie	5.49	3.25	0
13	48	Rookie	9.53	3.25	2
21	49	Star	8.18	3.25	1
7	50	Star	9.53	3.25	2
60	51	Star	5.49	4	1
12	52	Star	5.49	4	1
52	53	Rookie	8.18	4	1
36	54	Star	5.49	4	1
56	55	Star	9.53	4	1
57	56	Star	8.18	3.25	1
22	57	Star	8.18	4	1
29	58	Rookie	5.49	3.25	0
50	59	Rookie	9.53	4	1
23	60	Star	5.49	3.25	0

Table 4.7 Interacted observation result for general factorial design

	Welder			
	Rookie		**Star**	
	Electrode Diameter		**Electrode Diameter**	
Wall Thickness	***3.25***	***4.00***	***3.25***	***4.00***
5.49	0 0 0 0 0	1 1 1 1 1	1 0 0 0 0	1 1 1 1 1
8.18	2 2 2 2 2	1 1 1 1 1	1 1 1 1 1	1 1 1 2 1
9.53	2 1 2 2 2	1 1 1 1 1	2 2 2 2 2	1 1 1 1 1

4.3.4.3 Analysis of experiment results

Firstly, ANOVA was used to analyze experiment and observation results. In ANOVA Table, p values were considered in order to evaluate the effectiveness of main factors and interactions of factors in the failures. In addition, confidence interval level was decided 0.05.

Due to, p values were less than value of confidence interval, the following factors and interactions were indicated that have got critical effect in the welding failures:

- Wall Thickness
- Electrode Diameter
- Interaction of Welder & Wall Thickness
- Interaction of Welder & Electrode Diameter
- Interaction of Welder & Electrode Diameter and Wall Thickness

Related ANOVA is shown in Table 4.8.

The results of experiments were accepted due to the R^2 value (89.74 %) which denotes the confidence of model and R^2 (adj) value (87.39 %) which changes related to residual factors, were acceptable values.

Afterward, Main Effect Plot and Interaction Plots were used in order to determine proper levels of factors and their interaction. Figure 4.9 shows the related Main Effect Plot and Figure 4.10 shows the related Interaction Plot Graph.

According to Main Effect Plot Graph which shows in Figure 4.9;

- Failures are not affected greatly by two levels of welder factor
- Quantity of welding failures increase at 9.53 mm and 8.18 mm thicknesses of wall
- Quantity of welding failures increase at 3.25 mm diameter of electrode

Table 4.8 ANOVA table of factorial design

```
General Linear Model: Observations versus Welder; Wall Thickness; Electrode Diameter

Factor              Type   Levels  Values

Welder              fixed       2  Rookie; Star

Wall Thickness      fixed       3  5.49; 8.18; 9.53

Electrode Diameter  fixed       2  3.25; 4.00


Analysis of Variance for Observations, using Adjusted SS for Tests

Source                             DF   Seq SS  Adj SS  Adj MS      F      P

Welder                              1   0.0667  0.0667  0.0667   1.33  0.254

Wall Thickness                      2   9.3000  9.3000  4.6500  93.00  0.000

Electrode Diameter                  1   0.2667  0.2667  0.2667   5.33  0.025

Welder*Wall Thickness               2   0.8333  0.8333  0.4167   8.33  0.001

Welder*Electrode Diameter           1   0.2667  0.2667  0.2667   5.33  0.025

Wall Thickness*Electrode Diameter   2   8.6333  8.6333  4.3167  86.33  0.000

Welder*Wall Thickness*              2   1.6333  1.6333  0.8167  16.33  0.000

  Electrode Diameter

Error                              48   2.4000  2.4000  0.0500

Total                              59  23.4000


S = 0.223607   R-Sq = 89.74%   R-Sq(adj) = 87.39%


Unusual Observations for Observations


Obs  Observations      Fit   SE Fit  Residual  St Resid

  4       2.00000  1.20000  0.10000   0.80000      4.00 R

 18       1.00000  1.80000  0.10000  -0.80000     -4.00 R

 24       1.00000  0.20000  0.10000   0.80000      4.00 R
```

According to Interaction Graph which shows in Figure 4.10;

- Welder and Wall Thickness Factors have got mutual interaction
- Welder and Electrode Diameter Factors have got mutual interaction
- Levels of Wall Thickness and Electrode Diameter Factors also have got mutual interaction.

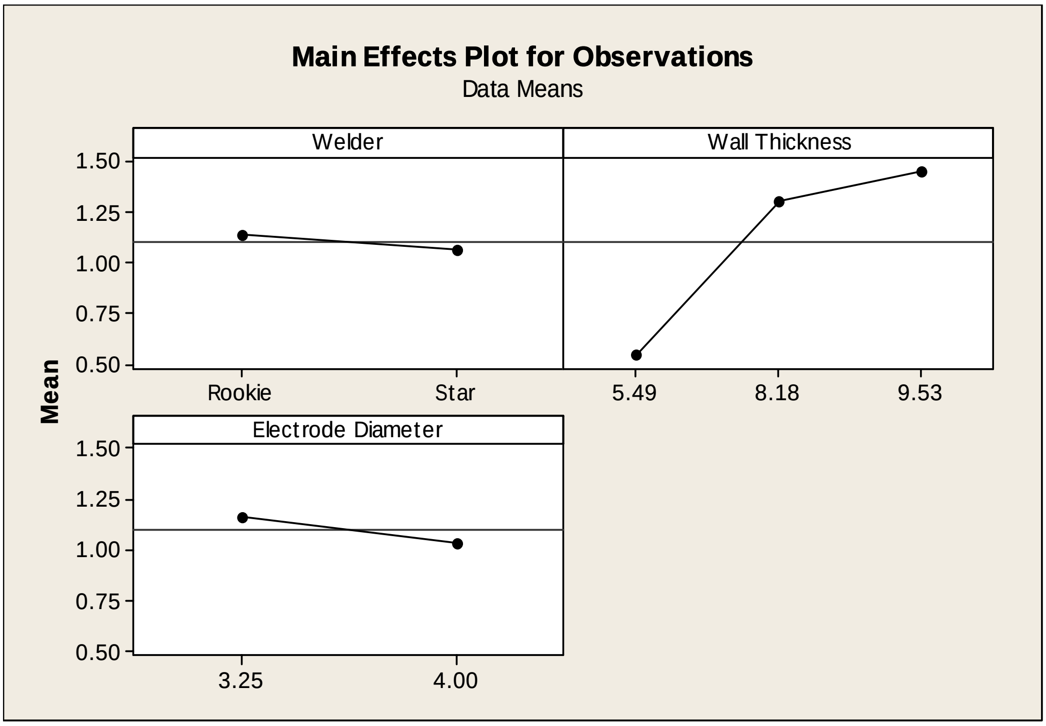

Figure 4.9 Main effect plot of factorial design factors

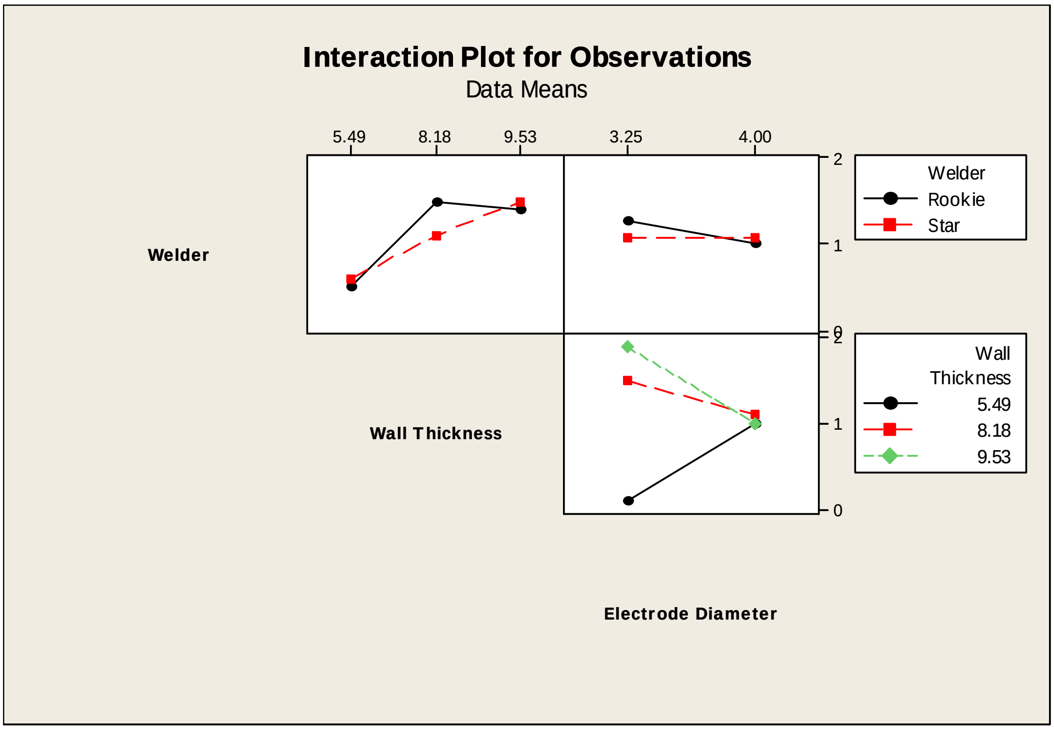

Figure 4.10 Interaction plot of factorial design factors

4.3.4.4 Recommendations for improvement

Due to the company required that the number of failures must be close to zero, the project team decided to recommend the following proposals for improvement:

- Hence, wall thicknesses were conditional upon to steam and water pressure, necessary improvement will be done at electrode diameter and welder.
- Rookie welders will weld 9.53 mm thickness of wall by using 4.00 diameter of electrode.
- Star welders will weld 8.18 mm thickness of wall by using 4.00 mm diameter of electrode and 5.49 mm thickness of wall by using 3.25 mm diameter of electrode.

4.3.5 Control Phase

After recommended improvements had been applied, welding process has been examined for a month. At these examinations, reduction was seen at welding failures. For that purpose, welding process had been controlled by using of binomial process capability.

The p control chart indicated that there was no point out of control limits. This situation verified that the process was in a state of control. The rate of defectives chart occurred that there was no correlation between defective percent and sample size. The cumulative % defective chart illustrated that the estimate of overall defective rate decrease from 6.75 % to 3.55 %. And lastly, histogram diagram illustrated that frequency of failure percent decrease from 10 % per day to 4 %per day. The p control chart, the rate of defectives chart, the cumulative % chart and histogram were illustrated in Figure 4.11. These charts were used to identify process capability, to analyze reality of collected data and to illustrate the rate of failures after improvements.

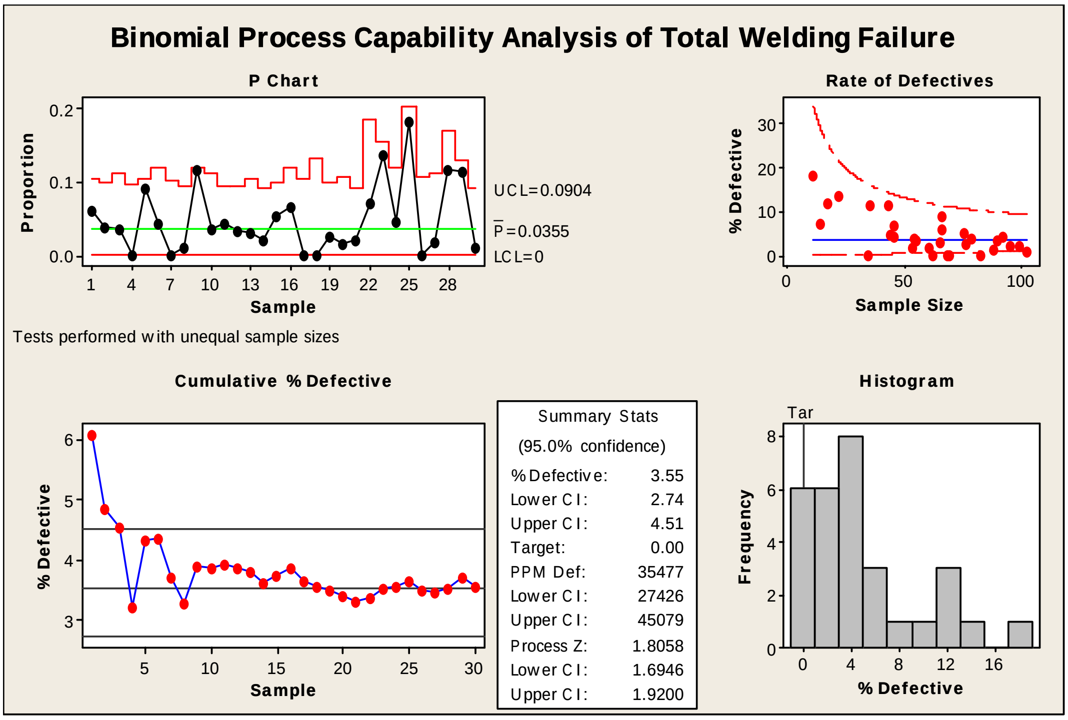

Figure 4.11 Process capability analysis of welding failures after improvement

Project team checked the results of improvement in terms of time and finance in order to see the real benefits of the improvement.

Real values are not used because of the company's confidentiality policy. Instead of those values, secondary values are used in proportion to the real values. So, percent status of achieved improvement shows the approximate real improvement percent.

2 items were taken into consideration for the resource cost account:

1. Labor Cost: Labor cost includes 1 welder, 1 assistant welder, 1 pipe assembly crafts master and 1 assistant pipe assembly crafts master per welding.
2. Consumable Materials Cost: Consumable materials cost includes the welding machine (Diesel welding equipment used at the site), electrode etc.

Total Welding Cost was calculated approximately 33.4 TL. In controls, reduction of welding failure percent was measured 3.2 % (From 6.75 % to 3.55 %). Total welding number was measured approximately 25000 from the beginning to the end of this project. So, reduction of welding failure percent meant that 800 welding failure was prevented and 800 x 33.4 TL = 26725 TL cost was saved. This saved cost was equal to 0.145 % of plant project budget.

This project was planned to finish approximately with 750000 man-hours. 800 welding failures are put in time on approximately 19200 man-hours. So this means that 2.56 % man-hours are prevented with improvements at project.

After that, the DPMO value of process was measured 34922.4 by using sigma level chart to see the improvement in sigma level. This measurement showed that sigma level was increased from 3.00 to 3.30. This proved that recommended applications were helped to increase quality level of process as illustrated in Table 4.9.

Table 4.9 Six Sigma level of process after improvement

No:	**STAGE**	**CODE**	**VALUE** **(Previous)**	**VALUE** **(After)**
1	Total Welding Number	*N*	1703	1804
2	Defective Welding Number	*D*	115	63
3	Defect Percentage	*DP*	0.06752	0.035
4	The number of independent opportunities for non-conformance per unit	*m*	1	1
5	Defect Per Million Opportunities	*DPMO*	67527.8	34922.4
6[3]	Sigma Level	σ	3,00	3,3

---

[3] Sigma levels are shown in the Sigma Level Convert Table which illustrated at Appendix B

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

Nowadays, Six Sigma is applied by different companies in many sectors. Significant improvements and benefits have been achieved while these applications. Construction sector is also one of them to apply Six Sigma in their processes.

In this study, a brief knowledge about the Six Sigma and Implementation of Six Sigma in the Construction Sector is addressed. Reduction of failures and increment of efficiency are taken as a goal in the process by implementing DMAIC methodology with statistical techniques.

In this study and examinations, there is no new statistical application is used and known statistical applications are used to solve and analyze problems during implementation of Six Sigma. Firstly, general information about Six Sigma, DMAIC methodology and previous applications is given. After then, DMAIC methodology is applied step by step in order to analyze the applicability of Six Sigma at processes of construction sector. For this purpose, the construction process is defined clearly, problems and CTQ of Six Sigma project is defined by tree diagram, flowchart and fishbone diagram. Then, necessary measurements are done about problem. Results of measurements are noted by tables like check sheets. After measurements are implemented, results of measurements are analyzed at analyze phase by the help of time graph, process capability analyze, histogram, p chart, pareto chart and six sigma level table. After then, factorial design is applied for improvements and recommended improvements are applied according to results. Then, improvements are controlled by using statistical tools which are p chart capability analysis, histogram and six sigma level chart.

After the applications is done, results of the improvements show that sigma level of welding process is increased from 3.00 to 3.30 by approximately 50% decreasing in welding process failures (from 6.752 % to 3.5 %). And separately, improvement of welding process brings to save cost of plant project budget of 0.145 % and reduce

2.56 % man-hours of project.

This thesis is showed that Six Sigma can be implemented in construction sector and processes. To decrease failures in welding process, Six Sigma DMAIC methodology was implemented. Although defect rate was increased to 3.5 %, this rate is still huge defect rate. During the study, more than four causes, which were improved in this study, were defined for failures in welding process. Six Sigma is a continuous process therefore other causes (or maybe investigated four causes) should be analyzed to decrease defect rate under 1 % in the further researches. New improvements and new analyses should increase the firm’s sigma level.

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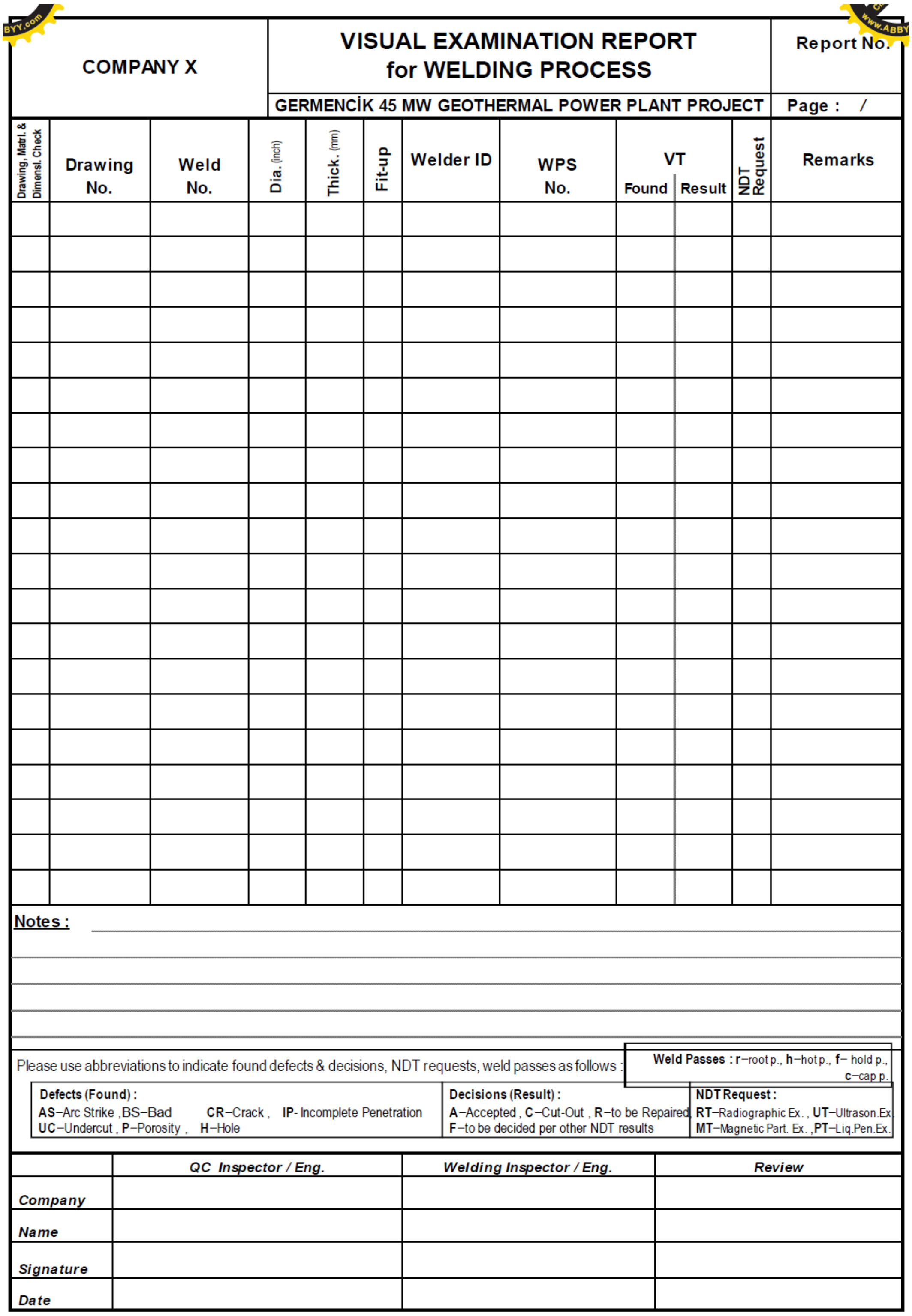
APPENDICES

APPENDIX A: VISUAL TEST RECORD PAGE



COMPANY X	**VISUAL EXAMINATION REPORT for WELDING PROCESS**	**Report No.**
	GERMENCİK 45 MW GEOTHERMAL POWER PLANT PROJECT	**Page : /**

Drawing, Matrl. & Dimensl. Check	Drawing No.	Weld No.	Dia. (inch)	Thick. (mm)	Fit-up	Welder ID	WPS No.	VT		NDT Request	Remarks
								Found	Result		

Notes :

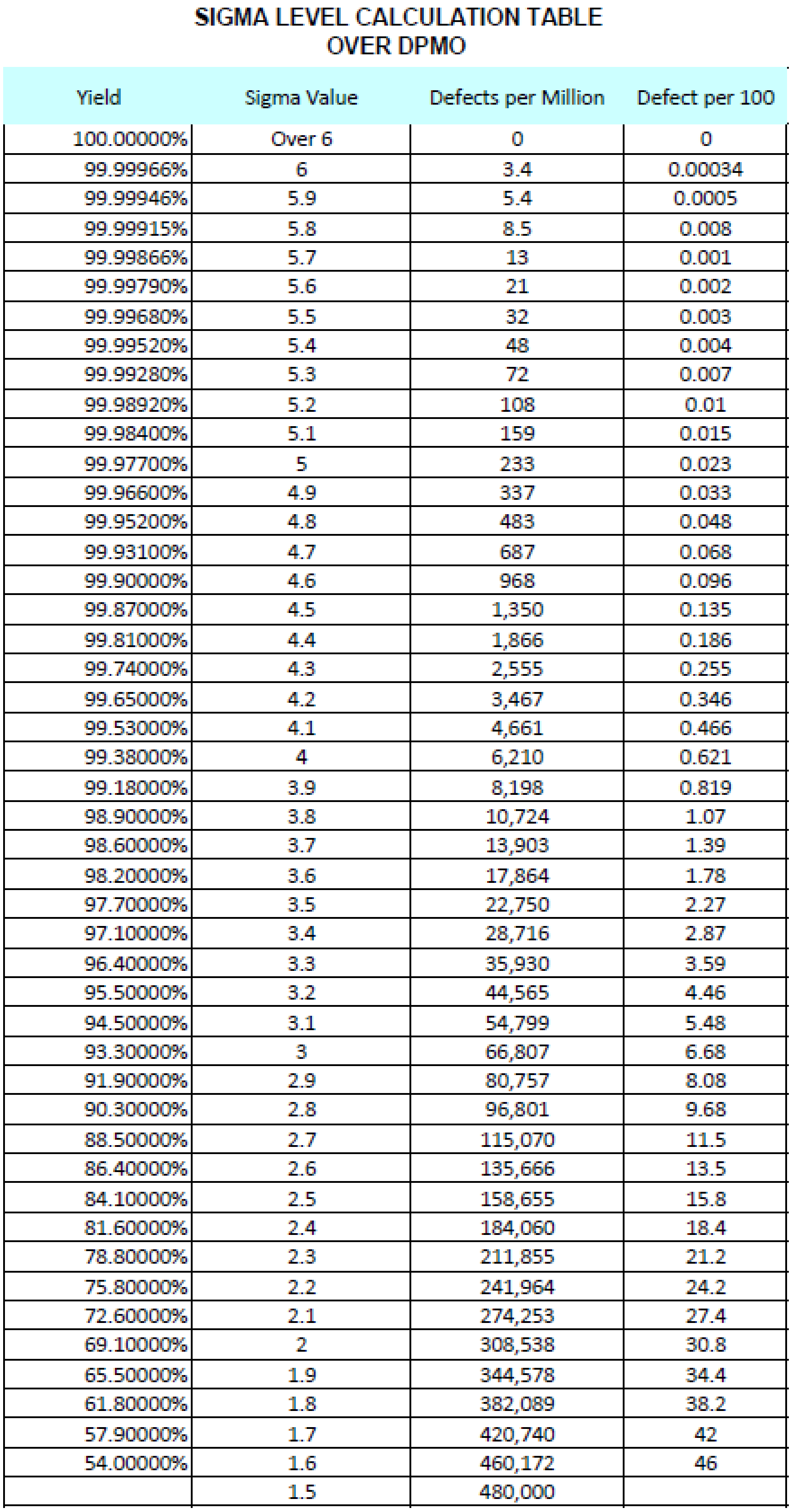
Please use abbreviations to indicate found defects & decisions, NDT requests, weld passes as follows :

Weld Passes : **r**–root p., **h**–hot p., **f**– hold p., **c**–cap p.

Defects (Found) : **AS**–Arc Strike ,BS–Bad **CR**–Crack , **IP**- Incomplete Penetration **UC**–Undercut , **P**–Porosity , **H**–Hole	**Decisions (Result) :** **A**–Accepted , **C**–Cut-Out , **R**–to be Repaired, **F**–to be decided per other NDT results	**NDT Request :** **RT**–Radiographic Ex. , **UT**–Ultrason.Ex. **MT**–Magnetic Part. Ex. ,**PT**–Liq.Pen.Ex.

	QC Inspector / Eng.	*Welding Inspector / Eng.*	*Review*
Company			
Name			
Signature			
Date			

APPENDIX B



SIGMA LEVEL CALCULATION TABLE
OVER DPMO

Yield	Sigma Value	Defects per Million	Defect per 100
100.00000%	Over 6	0	0
99.99966%	6	3.4	0.00034
99.99946%	5.9	5.4	0.0005
99.99915%	5.8	8.5	0.008
99.99866%	5.7	13	0.001
99.99790%	5.6	21	0.002
99.99680%	5.5	32	0.003
99.99520%	5.4	48	0.004
99.99280%	5.3	72	0.007
99.98920%	5.2	108	0.01
99.98400%	5.1	159	0.015
99.97700%	5	233	0.023
99.96600%	4.9	337	0.033
99.95200%	4.8	483	0.048
99.93100%	4.7	687	0.068
99.90000%	4.6	968	0.096
99.87000%	4.5	1,350	0.135
99.81000%	4.4	1,866	0.186
99.74000%	4.3	2,555	0.255
99.65000%	4.2	3,467	0.346
99.53000%	4.1	4,661	0.466
99.38000%	4	6,210	0.621
99.18000%	3.9	8,198	0.819
98.90000%	3.8	10,724	1.07
98.60000%	3.7	13,903	1.39
98.20000%	3.6	17,864	1.78
97.70000%	3.5	22,750	2.27
97.10000%	3.4	28,716	2.87
96.40000%	3.3	35,930	3.59
95.50000%	3.2	44,565	4.46
94.50000%	3.1	54,799	5.48
93.30000%	3	66,807	6.68
91.90000%	2.9	80,757	8.08
90.30000%	2.8	96,801	9.68
88.50000%	2.7	115,070	11.5
86.40000%	2.6	135,666	13.5
84.10000%	2.5	158,655	15.8
81.60000%	2.4	184,060	18.4
78.80000%	2.3	211,855	21.2
75.80000%	2.2	241,964	24.2
72.60000%	2.1	274,253	27.4
69.10000%	2	308,538	30.8
65.50000%	1.9	344,578	34.4
61.80000%	1.8	382,089	38.2
57.90000%	1.7	420,740	42
54.00000%	1.6	460,172	46
	1.5	480,000	