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SIX SIGMA APPLICATIONS IN DIFFERENT INDUTRIES

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ABSTRACT

At the present time, companies are faced with increasingly competitive environment in which the satisfaction and loyalty of customers are crucial factors in the success of any organization. Most of the companies search for management methodologies to improve their products and services, perfect their processes, decrease costs, improve the capital's profitability and customer satisfaction. These require the use of improvement methodologies, such as Six Sigma, which gives an opportunity to the companies to improve customer satisfaction and meet their expectations.

Six Sigma has been widely adopted in a variety of industries in the world and it has become one of the most important subjects of discussion in quality management. Six Sigma is a well-structured methodology that to find a root cause of quality problems and to reduce defects and process variability within the business processes using effective application of statistical tools and techniques. Also it can support a company to achieve expected goal through continuous project improvement.

The Six Sigma methods has two methodologies: DMAIC (Define, Measure, Analyze, Improve and Control) and DFSS (Design for Six Sigma). The one of the most widely known and applied model of Six Sigma problem solving approach is the methodology of DMAIC. In this study, the phases of DMAIC are explained in details.

This paper presents four case studies illustrating the effective use of Six Sigma to implement improvements about their problems. It describes in detail how the problem was defined and how the Six Sigma methodology was applied. It also shows how various tools and techniques within the Six Sigma methodology have been employed

This study indicates the differences and similarities of Six Sigma implementations in different industries. The end of this paper is concluded with the discussion of the results and suggestions for further research.

Keywords: *Six Sigma, Quality, DMAIC, Process Improvement*

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1. INTRODUCTION

In today's challenging business world the competition has intensified exponentially. Companies are trying to differentiate their products or services in order to gain more market shares. Some of the companies are contented with their situation in the market; being survived is enough for them, but for some of them aren't. This situation encourage some companies in order to be increase their profit. Another reason of wanting to be bigger is to make customer happier.

"Quality", "cost", and "time" are three key elements for being more requested. If the manufacturing process of products and services are set back for company, prices of them should be higher to cover its costs and consequently the customers can't afford these. Moreover, the delivery time is also important to sell the products or to provide services without delay. Lastly, quality is a significant element for the customers, customers can focus on the specification quality of a products or services, or how it differentiate to competitors in the market. In the present changing and highly competitive environment it is compulsory that the companies improve continuously themselves for growth and survival.

Continuous improvement has been playing important role in the quality world. Many definitions have been given and several philosophies have been developed in order to consider for the beginning, development, implementation, and management of continuous improvement.

Since many centuries, companies are trying lots of methods in order to catch the best level of quality. The Six Sigma method is a quality philosophy that is getting wide acceptance in the industry. It has followed the TQM movements to improve quality, delivery and reduce costs. The Six Sigma method is defined by Linderman etal. (2003) as "… an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer define defect rates" .

Many organizations have reported significant benefits today as a result of Six Sigma implementations. General Electric and Motorola which developed this organized and systematic methodology in 1986 are probably two of the most successful companies in implementing Six Sigma projects. Over the years, many companies, such as Allied Signal, Citibank, Sony, Raytheon, and Delphi Automotive have also reported unprecedented success from the Six Sigma initiative (Schroeder, Linderman, Liedtke, Choo, 2007). As of 2014, it is widely used in many sectors of industry, even though its use is not without controversy. The Six Sigma method research to improve organization’s products, services and processes by the way of continually decreasing defects and variations in the organization. It is a business strategy for understanding customer requirements, business systems, productivity and financial performance.

Technically, the Six Sigma method means a level of defects under 3.4 defects per million opportunities (DPMO) where sigma is the term which used to show the process variation around its mean (Linderman, 2003). The Six Sigma has a highly structured method of data collection and treatment which was provided by the way of using basic quality tools, like as, histogram, pareto diagram, process flow diagram etc. and combination of them with management support to large extent. Using the resources efficiently, performing the methodology of Six Sigma rigorously, defining and reducing the variance about products for standardization provide the success of Six Sigma project. Moreover, inclusion of senior management and a hierarchy of workers with the needed training are needed in order to accomplish for Six Sigma method.

The Six Sigma method has the potential of eliminating variability from processes and products by using a continuous improvement methodology (DMAIC) or a design/redesign approach which is also known as Design for Six Sigma (DFSS). These methodologies follow the following phases: Define (D), Measure (M), Analyze (A), Improve (I) and Control (C). Otherwise, DFSS employs the sequence Define (D), Measure (M), Analyze (A), Design (D) and Verify (V), during design/redesign projects.

The companies who are implementing Six Sigma methodologies have enhanced their profits in a significant ways which continues to rise. All of these positive effects were caused to choose the Six Sigma methods in order to write this thesis.

This study is one of the researchers that are about the methodologies of Six Sigma and the applications of Six Sigma in different industries. The purpose is to give brief information about the Six Sigma and to give and analyze examples about the application of Six Sigma in different industries.

After this introduction part, the literature of Six Sigma takes part in the second section. Starting from the history of Six Sigma, sequentially definition and principles of Six Sigma, Six Sigma organization structure, benefits and rewards of Six Sigma, researches about Six Sigma, Six Sigma applications in global companies and in Turkey, critical analysis or reorganization of findings take place in this section.

In third chapter, the methodologies of Six Sigma take part. The methodologies defined and each of phases of methodologies examined. In addition, after the examination, the phases of DMAIC methodologies explained with the example which is about improvements of the Six Sigma in the internal logistic area.

In fourth chapter the applications have been placed in order to set out in full to Six Sigma methodologies. There are four case studies; “Reduce Waste at Manufacturing Company”, “Ford Team Project Builds Relationships, Improves Quality”, “Using Six Sigma to Improve Complaints Handling”, “Delivering Record Products without Delays”. After explanation of case studies, the differences of the applications between explained case studies were determined and indicated the reasons of these differences. In addition, the similarities of applications between explained case studies also were defined and clarified what the result of these similarities. The results of that were showed by Tables.

In the last chapter, the conclusion of the thesis takes part. The general behaviors of the managers and the employees about the organizational issues in Six Sigma applications were discussed in this part. The limitation of Six Sigma method was divided 3 parts: Issues in strategy, Issues in organizational culture and Issues in training. In addition, future of Six Sigma was mentioned in this thesis.

2. OVERVIEW OF SIX SIGMA

In this chapter, Six Sigma is defined as a method of solving problems. Six Sigma's goals and metrics are discussed in the context of this chapter. History of Six Sigma is to touch and Six Sigma brought positive results with examples expressed.

2.1. Introduction

Six Sigma methodology is a project-oriented management to improve the quality of organizational processes, products and services deficiencies gradually. This is a systematic plan with a focus on improving the way of understanding the customer's requirements.

The requirement of the customer is the first priority in the organization. Quick response to customer requirements increases competitiveness in market. It also means profitability. The success of any company depends on the ability to guarantee the highest quality at the lowest cost.

Sigma 18 letter of the Greek alphabet, which for many years, is generally accepted symbol of the standard deviation. Standard deviation is a measure of the variation of the dispersion or distribution. If the population is typically distributed, 99.74% of the population is between ± 3 sigma from the mean. While most of the distribution companies using Six Sigma, as General Electric, Allied Signal, Honeywell, etc., takes place in mean and around mean.

2.2. History of Six Sigma

The roots of Six Sigma, measurement standard is on Carl Friedrich Gauss (1777-1855), which can be traced introduced the concept of the normal curve. Six Sigma as a measurement standard in product class variation can go back to 1920, when Walter Shewhart showed that three sigma from the mean value is the point where process requires correction.

Barney and McCarthy (2003) by Motorola University to determine the names in their book "The New Six Sigma"; "Many of measurement standards (CPK, zero defects, etc.) later came on the scene, but the credit for coining the term "Six Sigma" goes to Motorola engineer named Bill Smith. (Incidentally, the "Six Sigma" is a federally registered trademark Motorola)".

Six Sigma is first espoused by Motorola in the early 1990s, a business initiative. Current Six Sigma success stories, especially from the likes of General Electric, Sony, Motorola and

AlliedSignal, the attention of Wall Street have recorded and promoted the use of this business strategy (George, 2002).

Motorola had established itself as the world leader in the field of wireless communications products in the early 1970s. Shortly after Japanese manufacturers were competing on stage in the tough market conditions. These difficulties were mapped out in 1973, when Motorola realized itself not be capable to compete. In 1979, a renewal and growth company began under the leadership of CEO Bob Galvin. According to the vice-presidents were clear, to explain the situation: "Our quality stinks."

Improve the quality of the 10X objective was driven by elected leaders in each business unit. However, it was only on the production function is not easy to Figure out the main sources of problems.

Based on a story written in the network Motorola University, Motorola Manufacturing Institute was founded in 1984 (MMI) and began to institute educational programs. Quick satisfaction of top management, "Design for Manufacturability" (DFM) and "Six Steps to Six Sigma" curriculum were used for all technical staff around the world. Another Motorola engineer Craig Fullerton, developed and taught "Six Sigma Design Methodology" (SSDM - Ttoday as Design for Six Sigma and DFSS from most other companies).

Motorola’s managers set a more aggressive goal of 10X to 100X improvement after Six Sigma’s success. A one-day course called "Understanding Six Sigma" was then developed globally for all non-technical personnel and Six Sigma started to use on everything from measuring training defects to financial effectiveness at Motorola (Breyfogle, 1999).

The efforts led to Motorola receiving the first Malcolm Baldrige National Quality Award in 1988. Motorola attempted to achieve Six Sigma in all that they did in 1990, but it seemed to be stuck at 5.4 sigma (Barney & McCarty, 2003).

Six Sigma has evolved over time. It's more than just a quality system, such as TQM or ISO. Six Sigma is way of doing business. As Geoff Tennant describes in his book "Six Sigma: SPC and TQM in manufacturing and services"; "Six Sigma is a lot of things, and it might be easier to make a list of all the things that Six Sigma quality is not. Six Sigma can be considered as: a vision; a philosophy; a symbol; a metric; a methodology".

2.2.1. Some Six Sigma Success Stories

“Six Sigma has forever changed GE. Everyone- from the Six Sigma zealots emerging from their Black Belt tours, to the engineers, the auditors, and the scientists, to the senior leadership that will take this Company into the new millennium-is a true believer in Six Sigma, the way this Company now works.”- GE Chairman John F. Welch.

At General Electric, passion and drive for Six Sigma have achieved some very positive results. From the first year accelerated payback: $ 750 million by the end 1998, aesitameted $ 1.5 billion by the end of the 1999.

The financial "big picture", but this is just a reflection of the numerous individual successes GE has achieved part of its initiative Six Sigma. Some of the 1998 annual report of GE's shareholders based on the bottom;

- Team Six Sigma at GE lighting fixture repair problems in its accounts as one of its top client Wal-Mart cutting errors invoices and disputes by 98 percent, faster payments and increased productivity for both companies.
- GE Medical Systems design methods used Six Sigma to create a breakthrough in medical technology scanning. Now patients can have a full body scan in half a minute to increase in comparison with their use of devices and reducing the cost per scan.
- A group of employees of the lawyer through Six Sigma team leaders in a service business GE Capital led simplified contract review, which leads to more rapid completion of the proposals, in other words, the service response customersand annual savings of $ 1 million (Pande, 2000).
- GE reported an improvement in capacity of 12% -18% increase in operating margin to 16.7%, and 750 million in savings.
- Since July 1996, GE Plastics Singapore team, decreases discoloration of plastic articles. The team has raised the quality of two sigma to 4.9 sigma at four months $ 400,000 per year at the plant.
- GE Plastics Singapore team, starting in July 1996, reduced color variation in plastic products. The team raised quality from two Sigma to 4,9 Sigma over four months $400.000 a year for one plant.
- The first year deployment of Six Sigma scored GE Plastics benefit of $ 20 million. It's very impressivein 1996, as the first year of training costs are much higher than a year costs (Keller, 2001).

AlliedSignal / Honeywell began its activities to improve the quality improvement measures in the early 1990s to 1999 and saved more than $ 600 million a year, thanks to the wide staff training and the application of the principles of Six Sigma. The company says Six Sigma with increasing 6 percent performance in 1998 and with its record profits by 13 percent. Because Six Sigma efforts began fiscal year scopy market value of the company in a difficult has risen 27 percent per year in 1998 (Pande, 2000).

George (2002) had an article on USA Today (1998) is a difference of opinion about the value of Six Sigma in “Firms Air for Six Sigma Efficiency” in his book. Some of the quotes from the article as follows:

- “Six Sigma is expensive to implement. That’s why it has been a largecompany trend. About 30 companies have embraced Six Sigma including Bombardier, ABB(Asea Brown Boveri) and Lockheed Martin.”
- “Raytheon Figures it spends 25% of each sales dollar fixing problems when it operates at four sigma, a lower level of efficiency. But if it raises its quality and efficiency to Six Sigma, it would reduce spending on fixes to 1%.”
- “Lockheed Martin used to spend an average of 200 work-hours trying toget a part that covers the landing gear to fit. For years, employees had brainstorming sessions, which resulted in seemingly logical solutions. None worked. The statistical discipline of Six Sigma discovered a part that deviated by one thousandth of an inch. The company saves $14.000 a jet after correction. ”
- “Lockheed Martin took a stab at Six Sigma in the early 1990s, but the attempt so foundered that it now calls its trainees “program managers.” Instead of black belts to prevent in-house jokes of skepticism...Six Sigma is a success this time around. The company has saved $64 million with its first 40 projects. ”

Keller (2001) has given the following list of companies for Six Sigma; IBM, Bombardier, Asea Brown Boveri, DuPont, Kodak, Boeing, Compaq and Texas Instruments. As with GE, Motorola and Allied Signal, further examples of implementations based services include GMAC Mortgage, Citibank, JP Morgan and Cendant Mortgage.

2.3 What is Six Sigma?

There are many different opinions about what is Six Sigma. The most famous description for the matter concerned is that Six Sigma is one of the engineers and statisticians use to fine-tune the quality of products or processes, technical processes. Statistics and measures are important components of the methodology Six Sigma.

Furthermore, Pyzdek (1999) describes Six Sigma as Quality Digest and declares " Six Sigma is such a drastic extension of the old idea of statistical control as to be an entirely different subject." Other descriptions are about its goal of near-perfection in meeting customer requirement based on the assumptions. Six Sigma is a statistically derived performance target of operating with only 3.4 defects per million opportunities or activities suppressed. Motorola, which is one of the leaders of the world, is still trying to achieve this goal.

At the same time, other explanation for its striking effect cultural change can take place. Six Sigma is a company’s commitment at firms such as Motorola or General Electric. Therefore cultural change at issue is absolutely a valid way to describe Six Sigma.

All of these perspectives can be collected in one description for Six Sigma. Pande, Neumann & Cavanagh (2000) defined Six Sigma as "a comprehensive and flexible system for achieving, sustaining and maximizing business success".

Six Sigma is uniquely due to the understanding of the needs of customers in a detailed manner, disciplined use of facts, data, statistical analysis, management, improvement and rethinking business processes in detail, and careful manner. Mikel J. Harry, one of the developers of Six Sigma at Motorola, has calculated that the average company is considered suitable to the level of 4-sigma in the western world business culture, while the 6 Sigma is not uncommon in Japan (Harry, 2000).

Harrold (1999) compares sigma level in accordance with the industry and the type of treatment:

- Internal Revenue Service (IRS) phone-in tax advise – 2.2 σ
- Restaurant bills, doctors prescription writing, and payroll processing – 2.9 σ
- Average company – 3.0 σ
- Airline baggage handling – 3.2 σ
- Best in the class compannies – 5.7 σ
- U.S. Navy aircraft accidents – 5.7 σ
- Airline industry fatality rate – 6.2 σ

Sigma is a universal scale. This is a scale such as a balance measurement ounces or measuring temperature thermometer. Universal scale such as temperature, weight and length allow us to compare very dissimilar objects. The scale of the sigma makes it possible to compare completely different business processes in terms of the ability of the process to stay within the quality limits established for the process in question as well.

Six Sigma is not just an "improvement methodology". It is

- To achieve permanent control system of corporate governance and creating maximum performance for business and its customers, employees and shareholders benefit.
- A measure of the ability of each process definition.
- A targets for improvement, which reaches about perfection (George, 2002).

Pyzdek (2003) defined the system using its tools and effects, "Six Sigma is a rigorous, focused and highly effective implementation of prove quality principles and techniques. Incorporating elements from the work of many quality pioneers, Six Sigma aims for virtually error free business performance. "

2.4. Principles of Six Sigma

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

2.4.1. Increasing Customer Satisfaction

Customers are the first priority of Six Sigma. Therefore, Six Sigma begins to review the performance of customer satisfaction. The success of Six Sigma is defined impact on customer satisfaction and ratings.

Customer satisfaction is defined as a customer’s overall evaluation of the performance of an offering to date (Gustafsson, Johnson, & Roos, 2005). The empirical results indicate a significant relationship between customer satisfaction and cost-effectiveness as a whole 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 the necessary steps to ensure and improve customer satisfaction can be ordered as follows:

- Identification of the products and services which is provided by any person or department.
- Identification of clients for each products and services
- Identification of required to meet customer needs.
- Identification of processes.
- Frame of processes.
- Providing of continuous improvement by measuring, analyzing and controlling of improved processes.

On the way to success, increase customer satisfaction, is one of the principles of Six Sigma; because Six Sigma is a guide to success.

2.4.2. Data-Based Management

In recent years, despite the importance of the data, the measurement process, information management, information technology and so on, most of the business decisions are still based on the ideas and assumptions. The data-based approach to make decisions consistent with the objectives of applied behavior analysis (Pfadt, & Wheeler, 1995).

The first step is the application of Six Sigma is necessary to define indicators to measure key business performance. Later, these criteria are appiled to understand the critical variables and optimize results.

Six Sigma helps managers to answer two questions for basic support based solutions and solutions of data:

- The data / information, how can I use it to best advantage?
- What data / information really necessary?

2.4.3. Process-Oriented

Six Sigma is a methodology of innovation management to produce virtually all products, which are defect free, based on the process data. Activities for Six Sigma is not limited to process level or less to reduce the work at all levels of the company izderzhekeines and produce high quality products.

Activities for Six Sigma is not limited to process level but extended to all levels of the company to produce high quality products and reduce cost (Han, & Lee, 2002).

To perform a successful process:

- Goals should be clearly defined.
- It must be clear what the problem is.
- Key processes of the organization must be clearly defined, classified and mapped.
- Improving the skills to be developed in the organization.
- Improvements should be able to continue in the organization.
- Calculability should 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 of boundless business success. Cooperation with other companies with significant opportunities with their suppliers and customers or employees.

Large amount of time, waste of money and effort caused by disconnection or competition between groups, the need to work to add value for customers together.

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

2.4.5. Target to Perfect and Tolerate to Failure

It's not just for perfection without risks. If employees are afraid to take risks, or they are afraid of the results of their efforts, the required improvement can not be provided. Therefore the mentality should be communicated to employees and the requirements established for the quality of "Do not fear the results of their own efforts."

Six Sigma has a risk management. Therefore purposes may lead to failure of success but that risk management should always be in the business strategy to perfection.

2.5. Six Sigma Organization Structure

Six Sigma has its own organizational structure, which consists of a belt system. Each belt has a job description based on education. Generally, this organizational structure a champion, master black belt, belt and green belt back. Furthermore, there is a hierarchical coordination with each other.

2.5.1. Champion

Champions are high-level executives who understand Six Sigma and are committed to its success (Pyzdek and Keller, 2010). Champions lead Six Sigma teams and give them clear guidelines for the project. When the Six Sigma team faces with barrier at the project, champions help the team to overcome (Pande et al, 2000).

2.5.2. Master Black Belts

Master Black Belts are at the highest level, both soft and hard skills. They have several project experience in Six Sigma including advanced mathematical and statistical skills, analytical thinking. In addition, these people assist for six teams Sigma and as an adviser. At this point, in addition to their technical skills, human relations take an important role. They can run multiple Six Sigma teams (Pyzdek and Keller, 2010).

2.5.3. Black Belts

Six Sigma requires people who are well versed in mathematical abilities and statistical tools. People who are familiar with these various technical mean candidates for a black belt rank. Black belts play an active role in improving the process. They are responsible for the selection of projects, running improvements and the results. For this reason, they receive four months of training (Pyzdek and Keller, 2010).

2.5.4. Green Belts

Green Zone is the first rank of the belt system. The Green Belt is not trained as black belts. They have a basic knowledge of Six Sigma and its applications. Also they work a few projects every year. Since Green Belts are not trained intensively, they must be supported by Black Belt (Pyzdek and Keller, 2010). Conceptual organization of the belt is shown in Figure 2.1.

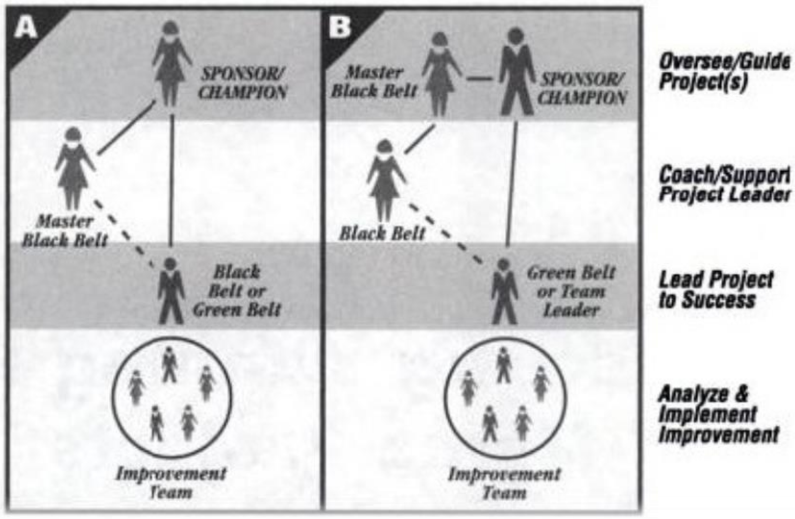

Figure 2.1 Six Sigma Belt Organization (Pande et.al., 2000).

In some cases, depending on the organizational structure, companies adjust their belt system to adapt their organizational structure and culture. For example, in Xerox addition to Green Belts, firm recruits Yellow Belts. By doing so, not just a group but the whole organization understands what a Six Sigma is, how it works and why it is necessary for the company. Six Sigma is a top to down method; however it can not be succeed without full participation of all organization.

2.6. Benefits And Rewards Of Six Sigma

The observed main benefits Six Sigma:

- Appreciation to customers and shareholders.
- Improving organizational ethics.
- Increased marketplace viability.
- Organizational recognition.
- Significant reduction in defects.
- Institutionalization of the "process" mentality.
- Increased reliability and predictability of software products and services.

The potential benefits from the actual implementation of Six Sigma projects can include (Antony & Escamili, 2003):

- Development of reliable products, processes and services
- Decrease cost due to poor quality
- Better understanding of customer needs and expectations for today and tomorrow
- Decrease of the product / service design and development time
- Improve process efficiency, stability and performance, etc.

In addition to these awards and achievements; Using the findings from the literature, we can say that Six Sigma has the advantage over the organization and the employee follows (Düğme, 2008).

Organization

- Bottom line cost savings
- Improving the quality perceived by the customer
- World class standard
- The reduction of cycle time
- Common language throughout the organization

Staff

- Improved knowledge and skills
- Wide range of tools and techniques

"Success Stories" by Motorola and General Electric (GE) from realization of Six Sigma result are as follows:

For more than ten years, Six Sigma implemented results from Motorola:

- Saved more than $ 11 billion in production costs.
- Increased productivity an average of 12.3% per year.
- Decreased the cost of poor quality by more than 84%.
- Eliminated 99.7% of in-process defects.
- Implemented a set of annual growth of 17% in sales, profits and stock prices

GE also provided in the 1997 annual report the following: The benefits of these Six Sigma example (Breyfolge, 1999):

- Business-plastic, through a rigorous process of working Six Sigma, 300 million pounds of new capacity (the equivalent of "free plant"), saved $ 400 million investment and will save another $ 400 million in 2000.

Savings and benefits of the project on the initiative of Six Sigma methodology have been widely reported. Table 2.1 summarizes the organization, projects, services, improvements and savings through the implementation of Six Sigma methodology in production is achieved on the basis of an extensive survey of the literature on Six Sigma.

Table 2.1. Reported Benefits and Savings from Six Sigma (Kwak, 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 Productivity	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

2.6.1. Benefits of Six Sigma in Manufacturing Sector

The main concerns are reducing defects and prevents rework in the production environment. More reliable products, improve product quality, customer satisfaction, reduced production costs and warranty claims are the expected results (Kwak, 2006).

2.6.2. Benefits of Six Sigma in Financial Sector

Department of Finance and the credit department to be under pressure to reduce the cycle time of cash collection and changes in collection efficiency in order to remain competitive. Typical Six Sigma projects in financial institutions include improving accuracy of allocation of cash to reduce bank charges, automatic payments, improving accuracy of reporting, reducing documentary credits defects, reducing check collection defects, and reducing variation in collector performance (Kwak, 2006).

2.6.3. Benefits of Six Sigma in Healthcare Sector

The health sector and Six Sigma principles are matched very well because of the healthcare nature of zero tolerance for errors and the potential to reduce medical errors. Some of the successful implementation of Six Sigma projects are to improve the timeliness and accurate claims reimbursement, streamlining the process of healthcare delivery and reducing the list of surgical equipment and related costs

The radiology film library at the University of Texas MD Anderson Cancer Center also adopted Six Sigma and improved service activities greatly. Also in the same institution's outpatient CT exam lab, patient preparation times were reduced from 45 min to less than 5 min in many cases and there was a 45% increase in examinations with no additional machines or shifts (Kwak, 2006).

2.6.4. Benefits of Six Sigma in Engineering and Construction Sector

In 2002, Bechtel Corporation, which is one of the largest construction and engineering companies in the world, the savings of $ 200 million with an investment of $ 30 million in its Six Sigma program to identify and avoid defects and rework in everything from design to construction on-time delivery of employee payroll (Eckhouse, 2004). Such as, Six Sigma has been implemented to streamline the process of neutralizing chemical agents, and in the framework of the national project to optimize the management of telecommunication costs and schedules (Kwak, 2006).

2.6.5. Benefits of Six Sigma in Research and Development Sector

Objectives of implementing Six Sigma in R & D departement to decrease costs, increase speed to market, and improve R & D processes. To measure the effectiveness of Six Sigma, the company brought the review of data, improved project success rate and the integration of

R & D into normal work processes (Kwak, 2006). One survey showed that as of 2003 only 37% of respondents formally implemented Six Sigma principles in their R & D organization (Johnson, 2003).

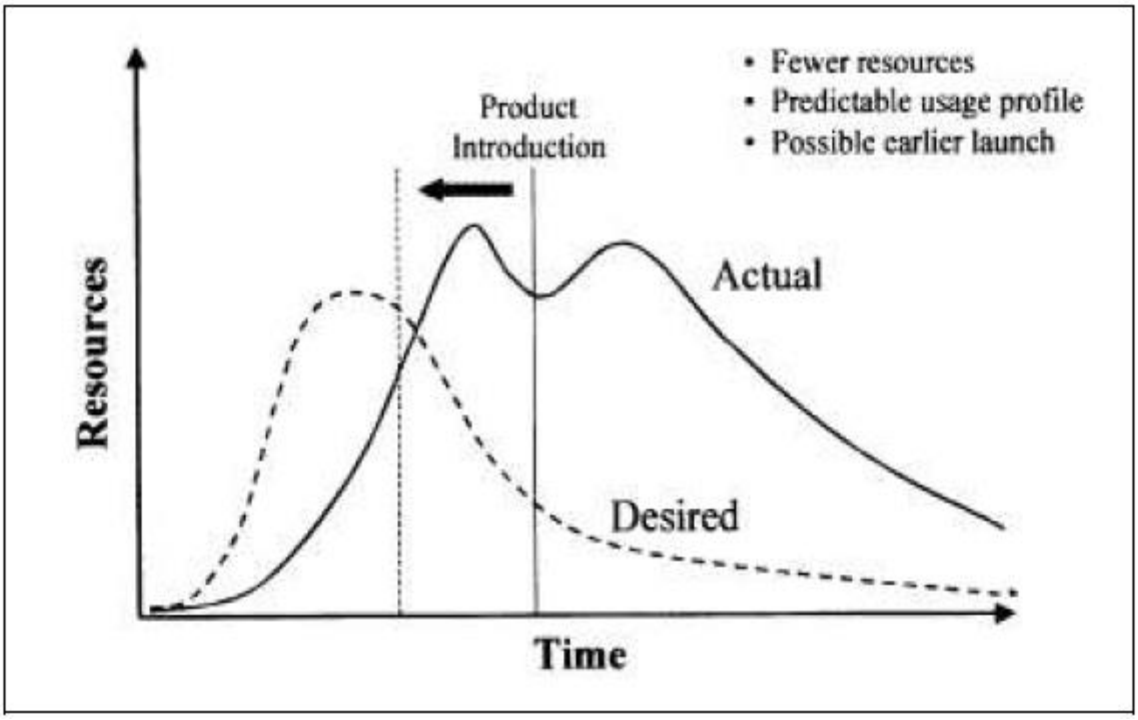

Figure 2.2. Advantages of Applying Six Sigma in R&D Projects (Johnson,2003)

2.7. Researches About Six Sigma

Six Sigma approach is realized by a variety of companies from different industries. Six Sigma approach was considered and studied by many researchers and scientists.

In this section the study of Six Sigma approaches in production and service are described.

2.7.1. In Manufacturing

Most approaches are presented in the manufacturing industry. Six Sigma was developed in the manufacturing industry, as well as other quality approaches, and many studies have been done of Six Sigma in manufacturing sector.

Holtz, and Campbell (2003), examined a Six Sigma application about maintenance functions of Ford. DMAIC methodology is applied to the company.

Knowles, Johnson and Warwood (2004) deals with the successful implementation of Six Sigma methodology to improve in the UK (United Kingdom) large food producers. The business in question is the task of reducing the cost of their products to bring them manufactured in accordance with the cost of similar products by other European plants

Banuelas, Anthony and Brace (2005) also studied Six Sigma in manufacturing. In their study, the main goal of Six Sigma is to reduce waste. To prioritize potential areas of improvement is using Six Sigma. As a result, the project team will select one Six Sigma projects which is about identification, quantification and elimination of sources of variation, which leads to failure.

Sekhar and Mahanti (2006) investigated the application of Six Sigma in the manufacturing which is to improve the air quality in the foundry. Previous surveys found that the air quality affects life on the effectiveness of employees and on the ecological health of people around the foundry. For these reasons, Six Sigma methodology was applied to this factory.

Kumar, Anthony and Madu (2006), has become the research was to reduce casting defects in the engine, which is also about the production area. DMAIC methodology was used as a roadmap to tackle the problem.

2.7.2 In Service

Although, Six Sigma approach, especially in the manufacturing sector is used, there are many Six Sigma applications in the service sector. In these applications, service companies gain significant achievement in customer satisfaction, to save money, reduce maintenance time, etc.

Pandey (2007), examined about service sector and in research, conducted in a multinational bank located in the National Capital Region (NCR) of India. Implementation of Six Sigma helped the HR function to better perform this task in this study.

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.

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.

2.8. Six Sigma Application in Global Companies

Motorola, IBM, Texas Instruments and Xerox created the concept of the black belt, which is an expert in statistical methods. For example, Xerox Six Sigma program has provided 80's. As an improvement process developed in the 80's and 90's, Xerox explore various approaches to improve their business results. Six Sigma and lean concepts were adopted locally Xerox manufacturing and Supply Chain Operations in the late 90's. Because of success in 2002, Six Sigma and lean and taken to a company-wide strategy (Marx, Moscow, 2010); as a result, began intensive training belt in 2003 (Xerox 2010). Xerox has used this program to resolve a problem with a $500,000 printing press it had just introduced. Nearly 700 projects of high impact to the business carried out and brought significant financial benefits, thanks to the black belts in its organization; In addition to more than 2,000 people were as green belt and more than 11 000 employees in the yellow belt between 2003 and 2004 has been certified. Xerox also used Six Sigma methodology in their accounts receivables. As a result, Xerox generated more than $ 150 million in economic benefits in 2004 (Marx, M., 2010).

The most famous and popular of Six Sigma example is GE which introduced Six Sigma for the first time in June 1995, when Jack Welch invited Larry Bossidy for talks at executive board of GE. After this meeting, GE conducted a cost benefit analysis for the implementation of Six Sigma. The analysis showed that if GE were to raise its quality in Six Sigma, the possibility of cost savings was somewhere between $ 7 billion and $ 10 billion, which was in a large number 10 to 15 of sales. Welch implementing Six Sigma in GE announced in January 1996 (Process Quality Associates Inc, 2010). At the time, Welch created a mandate for Six Sigma in its management team "to get on board, or get out" (Linderman, Schroeder, et al, 2003). Consequently, Table 2.2 showed the financial impact of the program in the period from 1996 to 1998. This method also acts as a catalyst and helped the company to preserve $ 2 billion in 1999 (Kaya, S., 2010). Not only GE, but suppliers use this method.

Table 2.2. Impact of Six Sigma Implementation at GE (1996-1998)

	Increase	Percentage (%)
Revenues	$100 billion	11
Earnings	$9.3 billion	13
Earnings per Share	$2,80	14
Operating Margin	-	16,7
Working Capital	-	9,2

2.9. Six Sigma Applications in Turkey

Methodology of Six Sigma Sigma was adopted early at Motorola, Inc., which reported that over $ 17 billion of Six Sigma in savings as of 2006. In addition to Motorola, Honeywell International and General Electric put into practice of Six Sigma methodology. Recently, the method used and applied in many Turkish companies.

One of the leading appliers of Six Sigma methodology in Turkey is TEI Tusas Motor Industries which was fully adopted Six Sigma to quality management systems in compliance with international regulatory standards. The company has its delivery strategy on time with competitive prices with the implementation of Six Sigma through the continuous improvement of products and services, processes and quality management system (http://www.tei.com.tr).

Borusan Holding, steel pipes and flat manufacturer of steel, automotive and heavy construction equipment dealer, its Six Sigma journey within the broader corporate strategy of transformation began to reinvent itself again in order to perform in an increasingly competitive economy in 2002. The program has been credited with the creation of more than 38 million US dollars in financial benefits by completing more than 200 projects implemented Six Sigma community of more than 1,000 employees (www.borusan.com.tr).

Vodafone Turkey, a telecommunication provider as the use of Six Sigma in process design, process control and process improvement, as a strategy for managing since 2007. With the help of Six Sigma is Vodafone Turkey focused on priority projects developed customer satisfaction, improved teamwork throughout the company and gain a competitive advantage in the market.

Eczacıbaşı Vitra, one of the leading companies in the field of construction, Six Sigma is used in the collection and analysis of data for the purpose of technological excellence by eliminating non-value added operations, focusing on customer needs and the development of internal collaboration within the company.Benefits of Six Sigma program has Eczacıbaşı Vitra minimizes defects in the manufacturing process, and received a ranking fifth in the world building products market.

Arçelik A.Ş., which is one of the leading companies in Turkey home appliances industry, took the first initiative in 1998 to apply Six Sigma in manufacturing processes and production processes, and so extended to other processes in 2002. Six Sigma projects are designed and implemented with the coordination of the leader of Six Sigma at Arçelik. Six Sigma methodology used to improve processes, making processes transparent and manageable, establishing a decision making mechanism based on data, achieving a constantly profit increasing platform, combining organization and process objectives, achieving customer oriented approach and encouraging innovation at Arçelik (http://www.arcelik.com.tr).

Ford Otosan, a shareholder of the Ford Motor Company in Turkey, also uses the methodology of Six Sigma in their service center. The company is mainly, the development of service process used in customer-centric strategies Six Sigma, there by reducing the cost of poor quality and product defects to minimize. This is directly reflected in the 10% -40% cheaper advantage for the company's profits.

Bosch Bursa Diesel Plant is applied Six Sigma methodology with success in Turkey. It is one of four plants Bursa and manufactures automotive technology. With Six Sigma company's continuous improvement of internal processes has provided care for their customers satisfied and high quality standards (http://www.bosch.com.tr).

KalDer (Turkish Society for Quality) cooperates with the ASQ (American Society for Quality) in the introduction and dissemination of Six Sigma program to Turkish companies (www.kalder.org). Today, Six Sigma is used in many industries such as manufacturing, services, telecommunications, petrochemical, automotive, equipment, supplies, construction, etc.

3. METHODOLOGIES OF SIX SIGMA

Six Sigma uses two different types of methodologies, DMAIC and DMADV which objectives to analyse complementary aspects of business processes. Differences between these methodologies are aimed at reaching different business sectors concurrently but focusing them differently. In spite of single difference, they match up with each other during the analyzing processes and aim at the same goal which is improvement of business processes.

Both of these methodologies has their own guidelines and goals which are targeted at improving business processes by way of using of data collection and statistical tools. Although the methodologies are targeted the same thing, there are significantly differences between them which should be regarded by professionals in business environments (Mast,Lokkerbol,2012).

3.1. What is DMAIC Model

The DMAIC Model is one of the most important development models for Six Sigma approach which is the most feasible to the production part of a product or services.

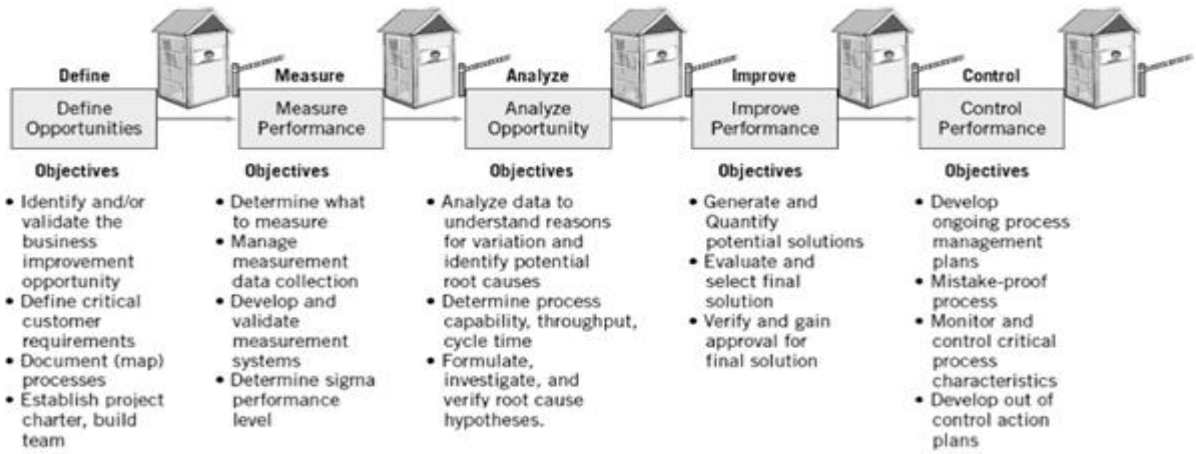

Figure 3.1 The DMAIC Process (Montgomery, 2008)

This methodology consists of following five steps:

Define the problem and customer requirements

Measure process performance and defects

Analyze the data collected and process map to determine root causes of defects and opportunities for improvement

Improve the process by designing creative solutions to fix and prevent problems.

Control the improvements to keep the processes on the new course (Lin, Chen, Wan, Chen, Kuriger, 2013).

Table 3.1.DMAIC Methodology (Chua, 2001)

Phase	Description
Define	Identify, evaluate and select projects; prepare the mission; and select and launch the team
Measure	Measure the size of the problem, document the process, identify key customer requirements, determine key product characteristics and process parameters, document potential failure modes and effects; theorize on the cause or determinants of performance
Analyze	Plan for data collection; analyze the data and establish and confirm the 'vital few' determinants of performance
Improve	Design and carry out experiments to determine the mathematical cause-effect relationships and optimize the process
Control	Design controls; make improvements, implement and monitor

Table 3.2. Key Steps of Six Sigma Using DMAIC Process(McClusky, 2000)

Six Sigma steps	Key processes
Define	Define the requirement and expectations of the customer Define the project boundaries Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs Develop a data collection plan Collect and compare data to determine issues and shortfalls
Analyze	Analyze the cause of defects and sources of variation Determine the variations in the process Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements Develop a strategy to monitor and control the improved process Implement the improvements of systems and structures

Steps of the DMAIC Model are explained below.

3.1.1. Define Phase (D)

The objective of the Define phase of DMAIC is to define the opportunities of project and to confirm or validate that it represents justify potential improvement. It is requested that a project be important to both the business and customers which means voice of customer (VOC). Who work in the process (stakeholders) and process' downstream customers need to agree on the potential suitability of the project (Montgomery, Woodall, 2008).

A project charter is one of the first item which should be completed in define phase. This is typically about up to two or three pages which consist of description of project, project's scope, project's deadline, preliminary description of primary and secondary metrics which will be used to evaluate success and regulate business unit, aims of corporate, the potential benefits of customer, the potential financial benefits of organization, milestones which should be complete successfully in the project, the team members and their roles and any useful additional resources to complete the project.

Normally in developing project charter the project sponsors play a remarkable role and they can use draft charter which basically consist of organization structure of team and to assign responsibility of team members. It provides complete the project unerringly.

Generally, a project charter should be able to completed 2- 4 working days by team but if it takes longer time; the project scope may be more detailed. In addition, a project charter should be consisting of identification the customer's critical-to-quality characteristics (CTQs) that are impacted by project. In the define phase, graphics are also useful to catch the details about project. The most common ones used involve flow charts and process maps, value stream maps and SIPOC diagrams which stand for Supplier/ Input/ Process/ Output/ Customer. Whereby these tools, what needs to be changed or improved in the process are much visual and understanding details are more effortless. Especially in the non-manufacturing environments are taken into account these diagrams such as banks, financial institutions, accounting firms, e-commerce, hospitals, governmental agencies and service organizations, where the opinions of a process, system and thinking process are misunderstanding.

An action plan for proceed with other DMAIC phases will be needed to prepare by the team. This will consist of individual work assignment and temporal deadlines. Other significant matters being attention to the measure phase, as it will be performed next. Finally, the team also should focus on the following to prepare tollgate review of define phase: (Montgomery, Woodall, 2008)

- Are the symptoms at the center of the problem statement? On the other hand does the problem statement focus not on possible causes or solutions?
- Are all the key stakeholders identified?
- Does the potential financial affect positively on project?
- Has the scope of project been affirmed to make sure that it is neither too small nor too large?
- Has the team completed a high-level process map?
- Have any obvious obstacles which are prevented to complete the project been ignored?
- Is the action plan of team for measure phase of DMAIC admissible?

3.1.2. Measure Phase (M)

The objective of the Measure phase of DMAIC is to apprise and comprehend process state. This phase consist of collecting data on measure of quality, cost and throughput/cycle time. In this phase, developing a list of all of key process input variables (KPIV) and the key process output variables (KPOV) are important tasks. On the other hand, the KPIV and KPOV may have been determined transiently at least during the define phase of DMAIC. Nevertheless, identifying and measuring KPIV and KPOV also should be so important in measure phase. Significant factors may be spending time for performing various work activities and waiting additional processing. Deciding and collecting what and how much data, which should be useful data to make possible a thorough analysis and understanding of current process performance with adapt to the key metrics, are important tasks in this phase. During the measure phase, collecting data may be made widely known in lots of ways such as stem-and-leaf diagrams, scatter diagrams, histograms, run charts and Pareto charts. Data could be collected by reaching historical records, but this way sometimes may be unsatisfactory because of incomplete history or the methods of record keeping. The methods of record keeping can have changed day by day. In addition, the desired information is set at naught in many cases. Briefly, it is mostly necessary to collect current data by way of observational study or it may be done by sampling from the relevant data streams. In the system, using sampling way may come easier and more useful to many workers. In the specific organization such as transactional/ service businesses, it may be necessary to develop convenient measurement and measurement system to record the information. This is main difference between service and manufacturing systems. In manufacturing, the methods of measurement and system performance's data are usually already found; whereas the background information is often more clear in manufacturing than in services. The data collected are used as the basis for determining the current state or basic process performance. Moreover, the capability of the measurement system must be evaluated because the team should know that they are trying to solve real problem in which the performance of process is fine but the system of measurement is chapped. Additionally, the team needs exact data to solve the problem currently. A formal gauge capability study may be used to make measurement system analysis, in other words a designed experiment may be used to quantify the accuracy and variation of the measurement process (Montgomery, Woodall, 2008).

The process cycle time also can be divided into value-added and non-value added activities. It is more useful to evaluate an estimate of process cycle time efficiency where

$$Process\ Cycle\ Efficiency = \frac{Value - Add\ Time}{Process\ Cycle\ Time}$$

The amount of time actually spent in the process to transform the form, fit, or function of product or service is termed the value-added time. The result of the value-added time activities , the stuff which the customer is willig to pay is occured.

A direct measure of how efficiently the process is converting the completed products or services is termed process cycle efficiency. Process cycle time is also relatedto the amount of work which is in-process through Little's Law:

$$Process\ Cycle\ Time = \frac{Work - in - Proces}{Average\ Completion\ Rate}$$

The average completion rate means that the output of the process over a defined time period, which also is a measure of the capacity.

At the final step of measure phase, if necessary the project charter should be updated by the team. Updating means reevaluate the project goals and scope, and reexamine structure of team. Moreover, the members of downstream or upstream business units may be expanded by the team, if activities of measure phase show that these individuals will be useful in following DMAIC phases. All of the issues and concerns which is impacted success of project should be documented and shared with the project owner or sponsor. On the other hand, the team may be make immediate recommendations to improve the process, like as elimination of non-value added activities or removing an unwanted variability source (Montgomery, Woodall, 2008).

After all, tollgate review of measure step needs to be prepared. Expectations and issues which are in also tollgate review include the following:

- Extensive process flow chart or value stream map should be prepared. In this chart or map, any major steps of process and activities of process should be defined with suppliers and customers. If suitable, growing queues' areas and accumulating work-in-process' areas should be defined and lengths of queue, level of work-in-process and waiting time should be reported.
- A list of KPIVs and KPOVs must be prepared and it must be consist of identification of how the KPOVs coupled with customer satisfaction or the CTQs of customer.
- Capability of measurement systems should be documented.
- If making any assumptions during data collection, it should be noted.
- The team could be responding some requests and questions like as, "Explain, where does that information come from?", "How did you realize that the data should be collect?", "How do you validate your measurement system?" and "Did you collect enough data to make real-like estimation of process performance?".

3.1.3. Analyze Phase (A)

The objective of the Analyze phase of DMAIC is to use the data from Measure phase to start to designate the cause and effect relationships in the process and to comprehend the different source of variability. In addition, the objective of this phase is to establish the potential causes of the defects, quality problems, cycle time and throughput problems, customer issues or waste and inefficiency which motivated the project. Separating the source of variability into common and assignable causes is also important task in Analyze phase. Process is changed to remove a common cause of variability during removing assignable cause which often includes eliminating a specific problem. Insufficient training of personnel processing insurance claims is caused a common cause of variability; concurrently a tool failure on a machine is caused an assignable cause (Montgomery, Woodall, 2008).

Historical data or the data collected in the Measure phase are used by the Analyze phase tools.

These data are usually very important in providing tips about potential causes of the problems which the process is experiencing. Progressions and actually defined specific improvements are result of these clues.

In most cases, tips to the factors affecting performance are already available from define and measure phase. The team may be demonstrated the problem though isolating to one group and that group is using older equipment. Either they may be analyzed the process map and they have revealed some fairly apparent sources of inefficiency and retardation in the process. Anyway, depending on these two reasons it is insufficient to say that is the cause of problem. One of is the reasons, uncertainties and hypotheses should be confirm with information in all phase of DMAIC. It is not just enough that the team affirm these factors are present; the team also must confirm that changes in these factors largely impact the outcome. The other objective of Analyze phase is to identify root causes, which has to be deeper. There are some of techniques to determine potential root causes. One of them is brainstorming, which is used between team members. While brainstorming, all of the team members prepare a large list of factors which could reasonably affect performance. This list consists of any factors that were revealed in the measure phase. Another popular technique is the 5 Whys. This technique includes repeatedly asking “why?” until it no longer makes sense to do so.

In most cases, the aim of the Analyze phase is to find out and comprehend tentative relationships between process variables and developing insight about potential process improvements. A list of specific root causes and opportunities should be prepared because these are worked up for action in the Improve phase where strategy of improvement will be enhanced and tested.

Statistical tools are also potentially useful in the Analyze phase. Some of the statistical tools are graphical data displays, control charts, hypothesis testing and confidence interval estimation, regression analysis, designed experiments, failure modes and effects analysis. Another powerful tool is discrete event digital simulation in the Analyze phase. Although using of it is not contained to those types of operations, it could be particularly use in service or transactional business. In factories, many successful applications of discrete event simulation in studying scheduling problems are using to improve cycle time and throughput performance. In this simulation model, a computer model is used to simulate a process in an organization. For example, what happens when a home mortgage loan application enters a bank could be simulated by a computer model. In this example, a discrete event is each loan application. The random variables are arrival rates, processing times and application's route by way of bank's process. The specific substantiation these random variables impress applications which accumulate at the different steps of process. Other random variables can be identified to formalize the effect of incomplete applications, defective information, different types of defects and errors, delays in procurement information from outside sources, like as histories of credit. By force of using the simulation model for loans, it can be easier to make reliable estimates of cycle time, throughput and other quantities of interest (Montgomery, Woodall, 2008).

While the team is preparing tollgate review of Analyze phase, they should be focused on following issues and potential questions:

- Which opportunities will be targeted for research in the Improve phase?
- What data and analysis promotes that researching the targeted opportunities and improving or eliminating them will have the requested outcome on the KPOVs and customer CTQs which were the main focus of the project?
- Are there other opportunities which will not be further evaluated?
- Is the project still going well with being careful to time and expected outcomes? Are there any additional resources required?

3.1.4. Improve Phase (I)

The team determines which KPIVs and KPOVs to study, decides what data to gather and how to display and research them, defines potential source of variability, and decide how to explain the data they procured in the Measure and Analyze phases. In the Improve phase, they give way to creative consideration about specific alteration which may be in the process and other staffs which may be done desirable to effect on performance of process (Montgomery, Woodall, 2008).

In the first step of Improve phase, importantly people who are contained in performing process should be involved. The project team should not complete alone this phase. Actually, maintaining communication with people who take part in process is made sense along any Six Sigma quality improvement project. There are lots of techniques to brainstorm potential solution to controvert the determined root causes in Analyze phase. It is very effective to encourage the participants to go against rules and assumptions, pretext and think like children. Normally, more structured brainstorming exercising is preferable from between participants and usually participants can prepare significant list of ideas on their own.

In this phase, ideas are never juridifed and removed. Just because, firstly one idea could seem like nonsensical but after it can be lead to a related idea which can be ideal solution. Similarly, assumptions about what can or cannot be completed successfully should not be confirmed without confirmation.

In the Improve phase, there are many various tools to use. By using of flow charts and value stream maps, the process is redesigned to improve work flow and reduce bottlenecks and work-in-process. Sometimes, an operation will be useful if error-proofing designing operation is used only the right way. The most important statistical tool is design experiments in the Improve phase. Design experiments are able to be performed to an actual physical process or to a computer simulation model of the process. Which factors influence the outcome of a process and the optimal combination of factor settings are able to be determined by using designed experiments.

To improve a solution to the problem and to pilot test the solution are the other objectives of the Improve phase. The pilot test means a form of a confirmation experiment and the aims of it to appraise and documents the solution includes the project goals. The pilot test's outcome is caused repetitive activities which are the original solution being refined, revised and improved lots of times (Montgomery, Woodall, 2008).

During preparation tollgate review of Improve phase, it should be focus on the following:

- Sufficient documentation which includes that explains the way of problem solution is done.
- Alternative solutions' documentation was being taken to account.
- Results for the pilot test completely are analyzed.
- The pilot test results literally are implemented to the plan. It should also consist of any regulatory requirements, legal issues, personal concerns or the effect on other business standard practices.
- Convenient risk management plans and any risk of practicing the solution are analyzed.

3.1.5. Control Phase (C)

The objectives of the Control phase are to finish all unfinished work on the project and to transfer the improved process with a process control plan to the owners of process and other required procedures to be sure that the earning from the project are going to be institutionalized. The goal is to be sure that the gains will be helped to the process and the improvements could be implemented in different but similar processes in the business. The owners of process should be ensured the past and present data of process on process metrics, documents of training, operations and current process maps. It is necessary to quantify the financial benefits of project. The process control plan should be prepared like a system to pursue the implemented solution which involving methods and metrics for periodic controlling. In the Control phase, an important statistical tool is control charts which are included lots of process control plans on critical process metrics. Process owners also should be ensured the transition plan which involves a validation and it should be checked several months after completing process. Another important staff is to make sure that original results are still accessible and stable by this way the positive financial impact will be sustained. It is usual to encounter a problem in the transition to the improved process. The plan should be included the talent to respond quickly to unexpected defect (Montgomery, Woodall, 2008).

Defects are mostly happened in the weak links of procedure and if they can be followed carefully, they may be prevented and fixed before continuing process. Responding to a defect means to avoid a little fault before becoming a defect. Reducing defects to almost zero is in the best designed systems and Six Sigma can be reached it.

The Control phase is a small version of process management. A form of infrastructure had been building along the duration of the project and documentation, which includes exactly how they want to transform that structure on to the participants, is done in the Control phase.

The tollgate review for the Control phase should involve the following:

- The before and after results are in line which means data illustration with the project charter must be convenient. It is important because of to understand that were the original objectives accomplished or not.
- Is the plan of process control complete? For monitoring the process can procedures be used?
- Is all main documentation complete for owners of process?
- The lessons learned from project should be convenient.
- Opportunities which are stopped following during life of project should be listed. This list can be useful for future project. Inventing potential project continuously is very important because of keep on process improvement.

- Opportunities of results of the project may be used in different parts of the business.

3.2. What is DFSS?

- “predicting design quality up front and driving quality measurement and predictability improvement during the early design phases “ (As Treichler et al. ,2002),
- “ A disciplined and rigorous approach to design that ensures that new designs meet customer requirements at launch” (El-Haik and Roy,2005),
- “ A data driven methodology based on analytical tools which provide users with the ability to prevent and predict defects in the design of a product or service” (De Feo and Bar-El, 2002),
- “The major focus of DFSS approach is to look for inventive ways to satisfy and exceed the customer requirements. This can be achieved through optimization of product or service design function and then verifying that the product or service meets the requirements specified by the customer” (Antony and Coronado, 2002).

The set of steps determined are used in Design for Six Sigma, DMADV (define, measure, analyze, design and validate), to make sure reproducibility and continuous improvement. The objective of DFSS is to translate customer requirements qualitatively and quantitatively to specifications of product. DFSS focalizes to recommended designs influentially meet customer scorecards which are defined. The process of DMADV is redesigning process.

DFSS is an attitude for taking the process improvement and reduction of variability philosophy of Six Sigma upstream from manufacturing or production into the design process, where new products, services or service processes are developed and designed. DFSS is replaced insufficient available process or product and also is designed a new product or process. The products or services are maximizing performed during DFSS period. Another benefit of DFSS is to increase quality and speed of processes inside an organization. DFSS is used by organizations when a process, product or services had to designed or redesigned. The source of product and service defect is realized from the earliest staged of research and development by force of “designing in” performance of DFSS. Design for Six Sigma teaches people a coordinate approach which include to involving right people, asking right questions and using right appliances from the very beginning of any design project. All of the industry, product or process design methodology use design for Six Sigma. Software design and systems are modernized and existing performance of products are improved by DSFF (Mital, Desai, 2008).

Shortly, DFSS is a configured and keep under control methodology to commercialize the technology efficiently those results in new processes, products and services. DFSS contain whole development process from the definition of customer needs to the final release of the new product or services. Customer input is developed by way of voice of customer activities planned to identify what customer really wants, to prioritize on the strength of real customer wants, and to identify if the business can satisfy needs at a competitive price that will make possible it to make a profit. Customer interviews, direct interaction with and survey of the customer by way of focus groups, surveys and analysis of customer satisfaction data generate voice of customer data. The main objective of VOC is to develop a set of critical to requirements of quality for the product or services (Hekmatpanah, Sadroddin, Shahbaz, Mokhtori, Fadavinia, 2008).

Characteristically, DMAIC is used to succeed operational perfection; on the other hand DFSS is focalized improving results of business by enhancing the revenue of sales produces from new products and services and creating new opportunities of application for available ones. The reduction of development lead time, which means the cycle time for commercializing new technology and getting the resulting new products to market, is a significant gain from DFSS in many cases. Design for Six Sigma is mainly focalized on enhancing value in the organization. Operational Six Sigma also uses lots of the statistical tools in DFSS. Designed experiments are especially useful. Statisticians can make helpful contribution to DFSS by way of experimentation with main example and models of computer (Montgomery, Woodall, 2008).

A variation of DMAIC, DMADV (Define Measure, Analyze, Design and Verify) is used for DFSS by some organizations. Generally, DFSS provides some specific realization, for example, every design decision is a decision of business and during design period, performance of product, cost, and manufacturability are identified. Firstly, product is designed and released to production; it is unfeasible for organization of production to make it better. In addition, focalization decreasing variability in production only (operational Six Sigma) isn’t able to succeed whole business improvement. Customer requirements are main issue to focalize for DFSS while concurrently process capability takes into consideration. Especially, consistencies process capability and design requirements are fundamental. When inconsistencies between capability of production system and requirements at any level of design system are met, design changes or alternatives of production are considered to solve the conflicts.

De Feo and Bar-El (2002) determine seven elements of DFSS as follows.

- Drives the customer-oriented design process with Six Sigma capability
- Predicts design quality at the outset
- Matches top-down requirements flow down with capability flow up
- Integrates cross-functional design involvement
- Drives quality measurement and predictability improvement in early design phases
- Uses process capabilities in making final decisions

The differences between DMAIC and DFSS approach are also mentioned in the literatures. Through DFSS involves designing process to reach Six Sigma levels and is considered as an aggressive approach, but it still lacks a single methodology unlike Six Sigma. (Hoerl, 2004)

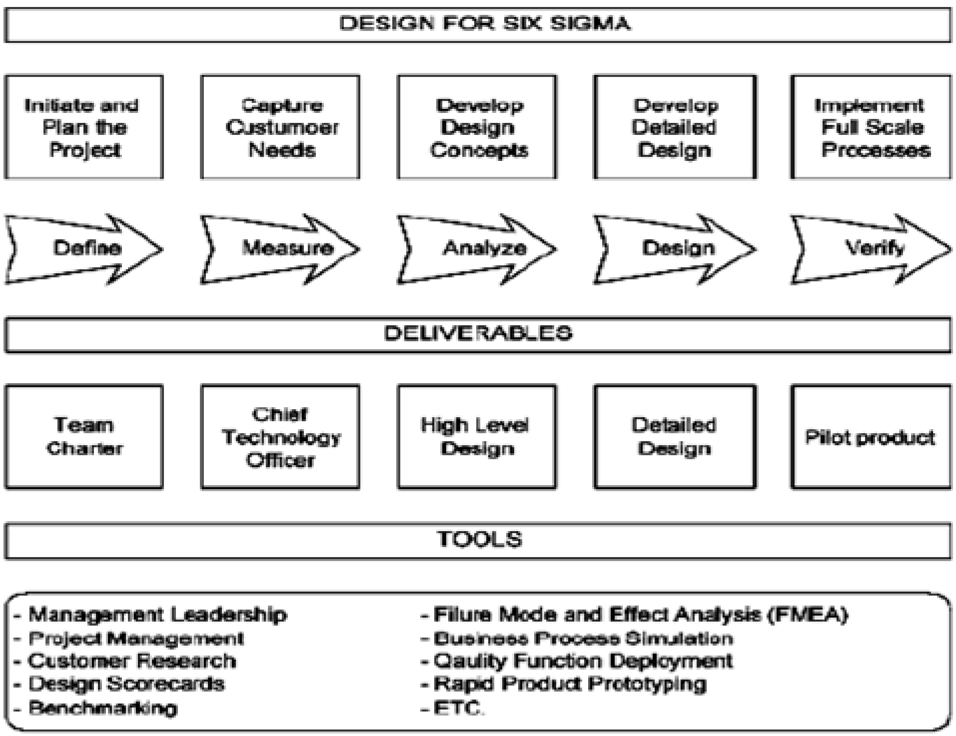

Figure 3.2. Five Step DFSS Process (Hekmatpanah, Sadroddin, Shahbaz, Mokhtori, Fadavinia, 2008)

There are different methodologies to use in DFSS as follows (Chakraborty, Tan, 2012).

- IDOV (Identify, Design, Optimize, Validate)
- ICOV (Identify, Characterize, Optimize, Validate)
- DCOV (Define, Characterize, Optimize, Verify)
- DMADO (Define, Measure, Analyze , Design, Optimize)

- DMADV (Define, Measure, Analyze, Design, Verify)
- DMADOV (Define, Measure, Analyze, Design, Optimize, Verify)
- DCCDI (Define, Customer Concept, Design, Implement)
- DMEDI (Define, Measure, Explore, Develop, Implement)

The other differences are:

- Ferryanto explains that DFSS is a methodology that takes into account the issues highlighted by the end customers at the design stage while DMAIC solves operational issues (2005).
- The benefits of DFSS cannot be evaluated easily and are procured in long time, on the other hand benefits of Six Sigma are stated in financial terms and procured more quickly.
- El-Haik and Roy clarify the differences that "The DMAIC methodology tends to provide incremental improvements in comparison to DFSS where there can be radical improvements (2005).
- " The projects improved through DMAIC methodology are constrained by the assumptions made during the development and design stages, whereas DFSS builds quality into the design by implementing preventive thinking and tools in the products developments process" (Smith,2001).

DFSS methodologies comprise some tools and techniques which are partly different from those of the DMAIC methodology. DFSS involves some tools of innovation like as the theory of creative problem solving, axiomatic design, and quality function deployment, which DMAIC does not.

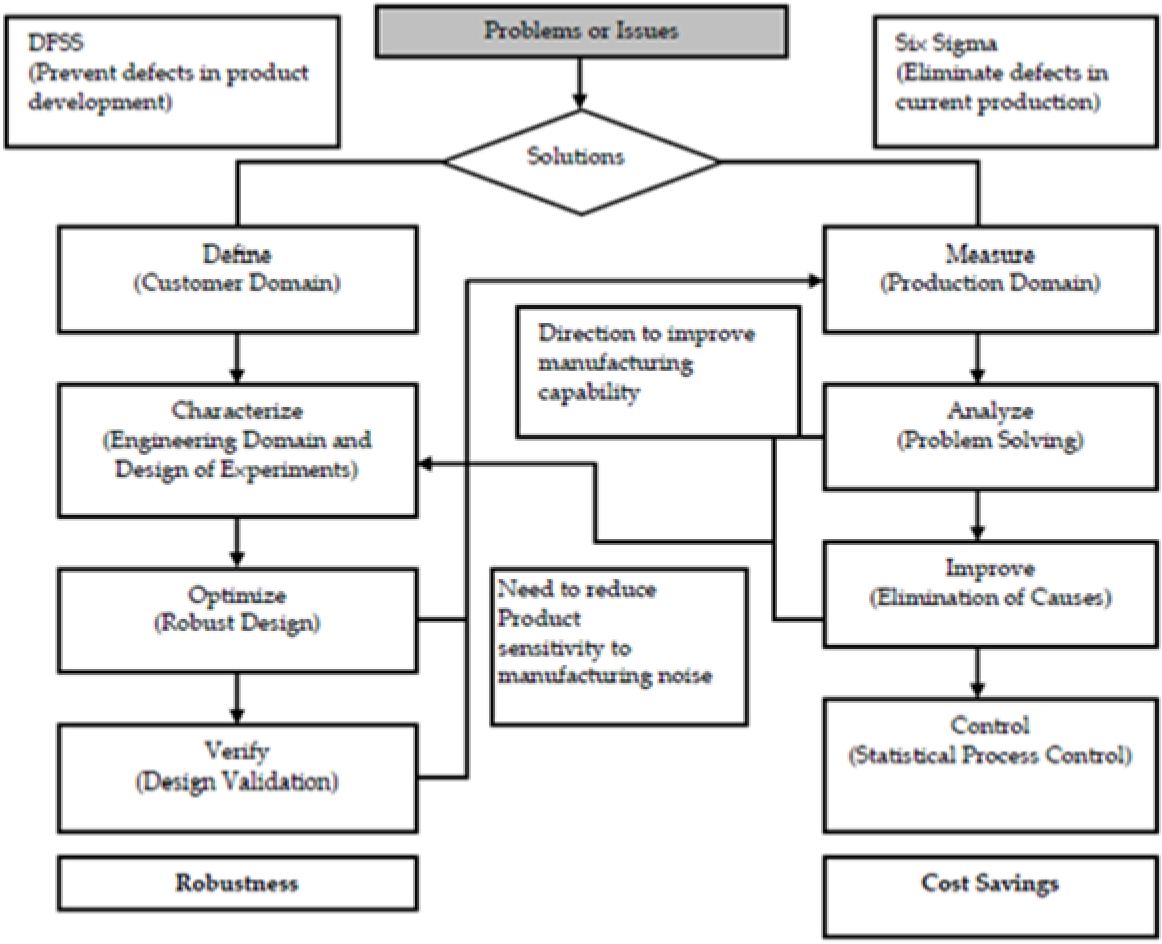

Figure 3.3. DFSS versus Six Sigma (Ferryanto, 2005)

3.3. Example of DMAIC Methodology

This case is helped to understand full of the methodology. Unlikely, it is almost impossible to write logistic case which will satisfy all customers of the case, because of that logistics is a comprehensive function with various activities. The application of the DMAIC methodology will represent for the internal logistics of a company. This company manufactures the heating equipment for domestic water, it is necessary to be success in the business sector. The satisfaction of the client is negatively impressed by lost production and being out of the delivery deadlines which were the result of not delivering materials in the right time, right place and right quantity. Milk-runs, point of use providers and logistical trains are generated the concept of internal supply. Milk-runs which are the one of the internal supply concept are the operators and their works deliver all the materials which are located in the ware house to the supermarkets of the internal clients. The request is came from the operators who have responsible for the transport of the materials from the supermarkets which are closed by the point of use, the final point of use for replacement materials; by the way of that the process is started. A barcode reader is used for an electronic request. The warehouse operators receive these electronic requests and put into place the needed materials in the logistic train. The several carriages can be combined to form a train based on defined route by the milk-run operators. After delivering requests, the trains are returned to the warehouse. In the warehouse the returned carriages are being separated, otherwise loaded carriages are being unified and a new route is started (Mijajlevski, 2013).

There route are being to deliver materials which are A, B, C. A and B routes run periodically but C route does not. The time of A and B routes is arranged 30 minutes; on the other hand, the time of C route is less than others. The defect means that the duration of A and B routes are out of 30 minutes. The consequence of that is caused a production stoppage. In addition, safety stocks are needed in the supermarkets because of the changefulness of the run of the routes. Checking over the time of the operation of the internal stockpiling of materials is the aim of this project (Mijajlevski, 2013).

Problem definition is “Between January and February 2011, roughly half of the routes’ practice time was more than the maximum allowed time which identified as 30 minutes. System confidence and the number of safety stock in the supermarkets of the internal clients are impressed negatively this delay in the delivery time.”

The project objectives are shown in the Table 3.3

Table 3.3. Definition of The Project Objectives (Mijajlevski, 2013)

Objective	January	February	Objective
Reduction of the DPMO	345.238	551.020	10.000
Increase in the sigma level	0,4	0	2,3
Reduction in the coefficient of the variation (%)	44	36	11,5
Reduction in the average time (min)	27	34	25
Coupling/decoupling (min)	12	12	0

After identify the project objectives, the anticipation of the customer on the route A were considered. The meetings were organized with the production managers.

Description of customer requirement contains the voice of the customer concept. Near to zero of production stoppages, half of decrease in the level of stock safety margin in the supermarket and near to zero of place established by the supermarkets, which means direct delivery to the point of use, were the requirements of the customer (Mijajlevski, 2013).

Consequently, the production stoppages were impressed the time of the route A because of safety stock needed in the supermarkets and stock out in the same supermarkets. (Mijajlevski,2013).

The time of the route A was measured in this case study. By the way of 148 analyzed routes for the March, it was clearly understood that 77 routes exceeded the limit of 30 minutes which means the level of defect of 52%, or DPMO of 516.779 (sigma level of 0) (Mijajlevski, 2013).

Cause and Effect diagram, shown in Figure 3.4, was used to define the factors which impress on the route time in the analyze phase. The session of brainstorming was regulated.

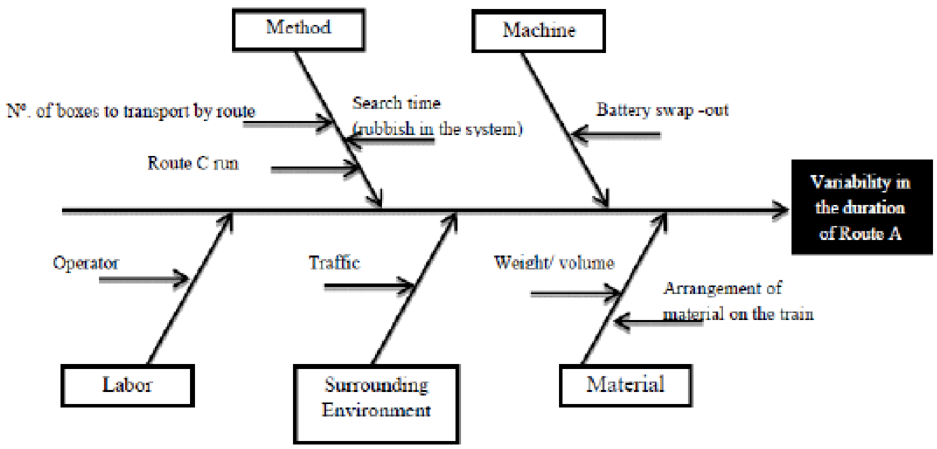

Figure 3.4. Cause and Effect Diagram (Mijajlevski, 2013)

The impact of the route C on the running time of the route A and the cause of number of boxes to deliver by route were measured by illative statistics. It was indicated that by the way of hypothesis when route A went before by run of route C, there were a remarkable differences in the elapsed time to duration route A. However, the run of route C always were followed by the run of route A because of delivering more boxes. The measurement of the impact of the cause of 'number of boxes to deliver by route' on the route was measured by the method of A linear regression. The connection with the depended variables which was 'needed time to run the route' and the independent variables which was 'number of boxes loaded onto the logistic train' was examined. Consequent of that, the elapsed time to run route rises with the number of delivered boxes (Mijajlevski, 2013).

The problem solutions which were studied before were suggested by the project team in the improve phase.

In Table 3.4 it is shown that a measurement of the impact and a requirement of the effort (Mijajlevski, 2013).

Table 3.4. Evaluation of The Impact and Effort of The Various Solutions Proposed

Solutions	Impact	Effort	Observations
The milk-run covers only A	9	4	Allocate Route C to another operator
Delivery of a fixed number of boxes per route	8	7	Necessity for a 3rd train
Relocate the heavy and outsized materials	3	4	Analyze in what location the heavy materials are to be found. Locate them as close as possible to the milk-run stop.
Eliminate the obsolete parameterizations from the information system	2	6	Analyze piece by piece the parameterizations in the system that are no longer used. Eliminate contradictory information.

The first two solutions were made a pilot test due to their possible impact. The solutions should be examined before their implementation in order to check their effects.

Through the pilot test period of 15 days for solution 'Process Route A w/o C', 79 routes were tested. After completion 79 routes shown that 12 routes took more time than 30 minutes so it means defect rate of 15% or DPMO of 151899. In addition, the variability of the route running duration was decreased from 37% to 26%. The time of decoupling and coupling operations which was 12 minutes had not a positive impact on the stopping time in the warehouse (Mijajlevski, 2013).

The pilot test of other solution was performed with the ‘Process Route A w/o C’ solution and the result of that only one of the 30 routes took more time than 30 minutes so it means defect rate of 3%, or DPMO of 33333 and sigma level of 1,83%. In addition, the variability of the route running duration was decreased from 26% to 14%. There was not a positive impact on stopping time in the ware house which increased 60%. The average time of duration a route was the same, 24 minutes.

It was decided to implement the other proposal which was ‘Quick change of carriages’ apart from other two proposals in order to decrease stopping time in the warehouse. The results of tests are represented in Table 3.5 (Mijajlevski, 2013).

Table 3.5. Client Requirements

Objective	January	February	Goal	Result	Status
Reduction of the DPMO	345238	551020	10000	33333	x
Increase in the sigma level	0,4	0	2,3	1,8	x
Reduction in the coefficient of variation (%)	44	36	11,5	14	x
Reduction in the average time (min)	27	34	25	24	✓
Coupling/decoupling(min)	12	12	0	0	✓

An improvement was implemented in all of the performances despite of that some of the goals were not achieved. A new test with the new solution namely ‘single route’ which was a combination of route A and route B, was tried by the project team because of long waiting time for a complete load. Decreasing was very little in the average time for routes and in the time variability from14% to 16% and in the number of routes’ duration above 30 minutes, nevertheless some positive effects were found. The stopping time between two routes in the warehouse decreased from 30 minutes which was the average value to 6 minutes while a full load was completed more quickly whereby on the route more stations stopped (Mijajlevski, 2013).

The automatic card system was used in order to determine and control the time of exit and the time of entry to the warehouse. Seven routes of the 190 were taken more time than 30 minutes which means a defect rate of 3,6% three months after implementation. The average time of the routes run was 24,4 minutes. By the way of these results it can be explain that the new process was stabilized (Mijajlevski, 2013).

The result of the performance improvements, the level of safety stock was decreased in the supermarkets. The elimination of two operators per day and the reduction of one transportation device which was rented from external company were the result of a combination of two routes like a single route. These reduction also gained advantages from the reduction in costs which was around 100 000€ per year (Mijajlevski, 2013)

The reduction of variation and defects are important for logisticians because of managing inventory, the trust of customer and sale. The origin of defects and variation were understood, the solutions for eliminating defects and variations were found by the way of Six Sigma. The aim of Six Sigma is to get closely as possible as to zero defects. Improvements are implemented in simple, effective, process-oriented and structured way by courtesy of net division of responsibility and aim to succeed remarkable results. It should be considered like a program for continual improvements which was implemented in the long term. The DMAIC implementation inside the project defined in this case study gained a financial benefits to the company which is around 100 000€ per year (Mijajlevski, 2013).

4. SIX SIGMA APPLICATION IN DIFFERENT INDUSTRIES

4.1. Case Studies

4.1.1. Reduce Waste at Manufacturing Company

In this case, the main objective of Six Sigma is to reduce waste. This effort is connected to the business' critical 'Y' of reducing production costs (Brue & Launsbry, 2003). The critical to quality characteristic (CTQ), which is the term 'Y' in this case, is most importance thing to any business in strategic terms. Here, Six Sigma team is formed around a black belt and three green belts, which are on the lookout, what was preventing one of the coating lines from achieving the business critical 'Y' goal. In the line, a wide range of coated products are produced to the automotive market. The coating line is a continuous process with equipment designed to allow a non-stop production during roll changes of Web materials and the unloading of finished rolls of production (Shephered, 1994). The number of line stops (stop off) and the amount of product wasted, which are identified by Six Sigma team, are two important indicators of the line performance. Each start generated waste so that operational time is needed for the key process to reach steady state running.

The turret re-winder, which is at the end of the coating system, winds up the 'Web' of film in controlled tension producing large rolls of output. There is often fails then move from one spindle to another. The aim of the Six Sigma project is to identify, quantify and eliminate the source of variation. This variation causes to failure to change over from one spindle or roll to another by the re-winder machine. The main goal is reducing manufacturing costs with to improve and sustain process performance.

Six Sigma DMAIC problem-solving methodologies were used in the case study. The project initially assumes that (Nave, 2002 and Berryman, 2002):

- The turrent re-winder's design is perfect.
- These designs satisfy the customer needs
- The market requirements are satisfied with the current process configuration.

The project's scope and goals were defined at this phase based on the customers' requirements. Define phase performed to four steps:

(1) The project's scope and boundaries were defined;
(2) The defects were identified;

(3) The team charter was defined;
(4) The project's effects were forecasted in monetary terms.

Black Belt projects are usually wider than the Green Belt projects. Here, the Black Belt project focuses on the entire coating line, while the Green Belt project is based on one aspect which is the turret re-winder performance.

The defects is defined that when one roll changed to another, the failure was occurred at the re-winder machine. Each failure causes loss of web tension and, thus, stops the line.

Preparation of Project Charter requires that team members to determine the following partially redundant elements which are helps team members to ward off critical elements of business-case (Rasis & Gitlow, 2002). The project charter was carried out to state the opportunity that exists. It cascades project description, objectives and possible financial benefits.

Business critical 'Y' defines the opportunity as it relates to the strategic business objective. The critical quality/cost tree helps Six Sigma teams to move from general needs of the customers or business strategy to the more specific requirements (Eckes, 2001). Figure 4.1 shows how generic business goals cascade into more specific potential Six Sigma projects. Reducing manufacturing cost is the critical business 'Y 'in this case.

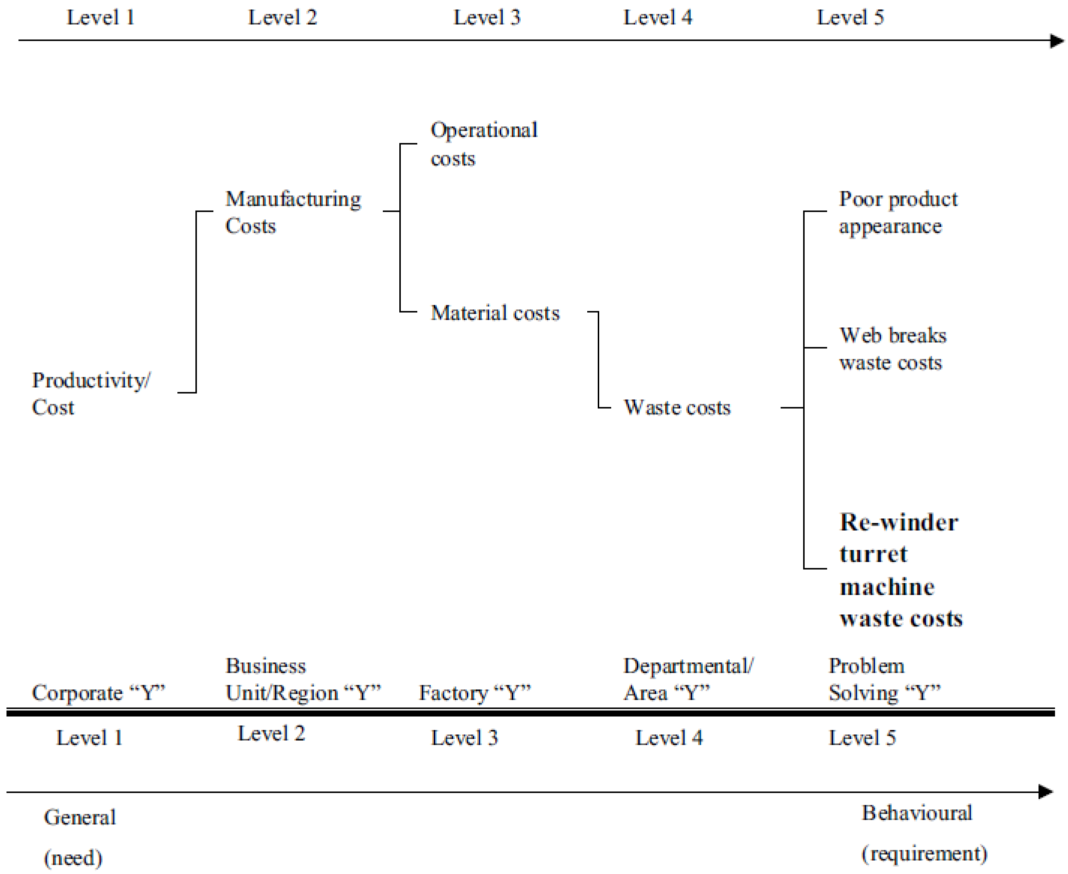

Figure 4.1. Critical to Cost Tree

The Six Sigma methodology begins and ends with customers. Projects should begin with the determination of customer requirements and it is essential to set project goals based on reducing the gap between the company's deliveries such as quality, delivery time, reliability and cost (Ba˜nuelas & Antony, 2002). The project team decided to target value which is three failures per week. As a result, the calculated capabilities in financial terms are measured at current situation minus project objectives (refer to Table 4.1).

Table 4.1. Estimated Financial Benefits

	Baseline	Goal	Entitlement	Units
Stop offs	11	3	3	Occ/week or m2
%Gold Star	63	75	75	%
Cost of poor quality	£1210	£330	£11	1 stop off = 80 m 1 metre waste = £110 waste material
Total opportunity =£58 080 (Annual) saving goal = £42 240 (based on 48 weeks)				

This project is located on the re-winder and leaves out a stop line with other causes. A champion, a Master Black Belt, a Black Belt, a Green Belt and six team members (people from maintenance, operators and a line supervisor are members of the Six Sigma team in this case. Besides that the supporters, who are from different department, stressed the importance of acquiring knowledge in maintenance as a key to the success of this project.

Before reach to next step, the team guarantees that the following deliveries:

- The business goals linked to process
- The team identify CTQ and customer characteristics
- Process outputs linked to customer requirements
- The project’s purpose, goals, benefits and plan were defined in project charter.
- Financial benefits were calculated based on the target values.

The measure phase aims to display the current process and establishing metrics.

The process of displaying shows a picture of the steps that is necessary to the output. All value added and non-value added steps are provided by process mapping which shows key process inputs 'X' and outputs 'Y' (Breyfogle, 1999). The flow chart, the SIPOC (supplier, input, process, output, customer) diagram and standard operation procedures (SOPs) are a few process mapping tools. In this case, SOP is used for process mapping. This tool provides a visual representation of the steps for understanding of the re-winder operation. Figure 4.2 shows process mapping.

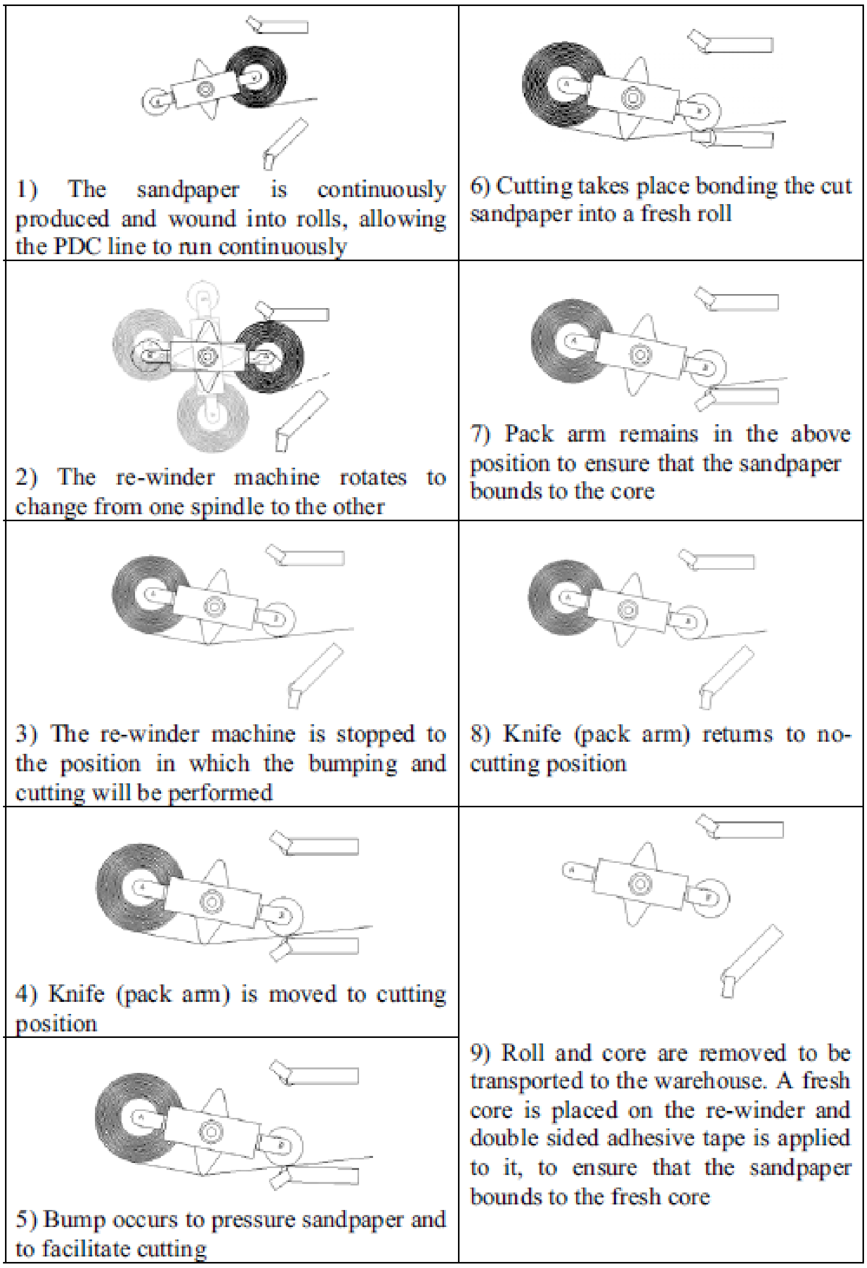

Figure 4.2. Process Mapping

The current status of the process performance level is 1.2σ or 88.5% yields in the long term. The metric established for the re-winder's performance is a passed or failed chop-over (discrete data).

A Pareto plot of defect was generated to identify any possible trend in failures within the process of re-winder. Pareto analysis shows most products have similar share of inconsistencies (as in Figure 4.3). Thus, it is difficult to link a relationship between the process and the product characteristics.

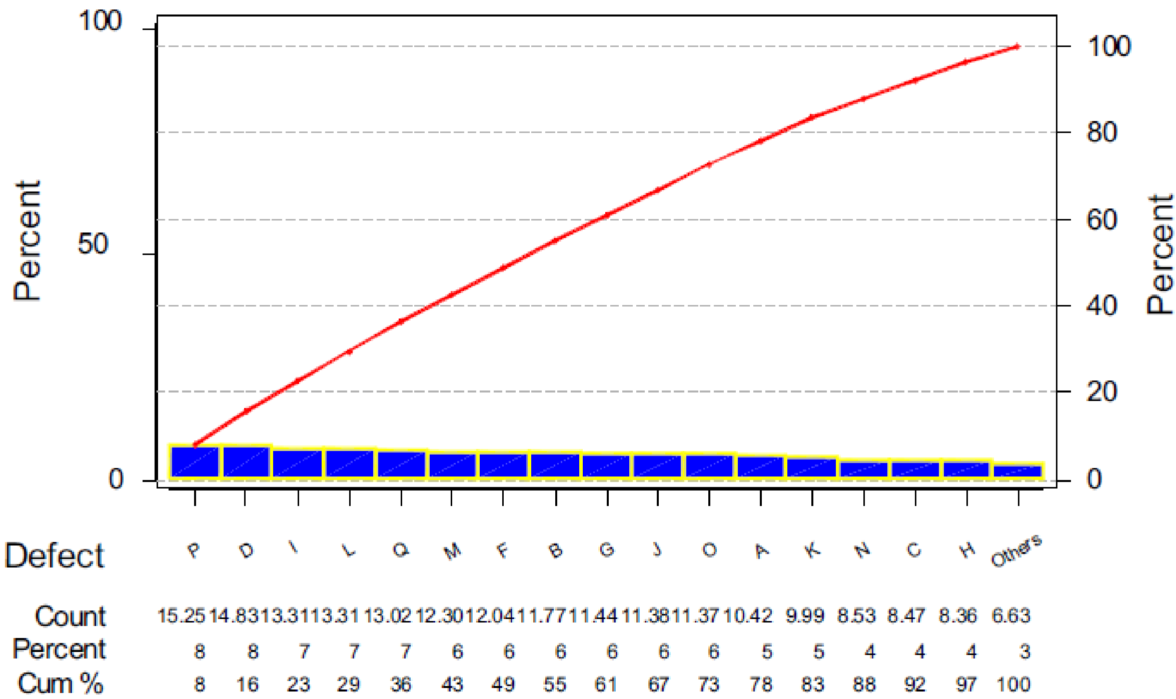

Figure 4.3. Re-winder Pareto

Continuous production of information is delivered more information to a given sample so that the team is committed to choose continuous data information over discrete information. The re-winder Web cutting operation has longer cycle time which is the higher probability to fault. Therefore it seemed to be a good indicator of operating results. On the other hand, cut cycle time was found that less than failures when operation worked properly, as in Figure 4.4.

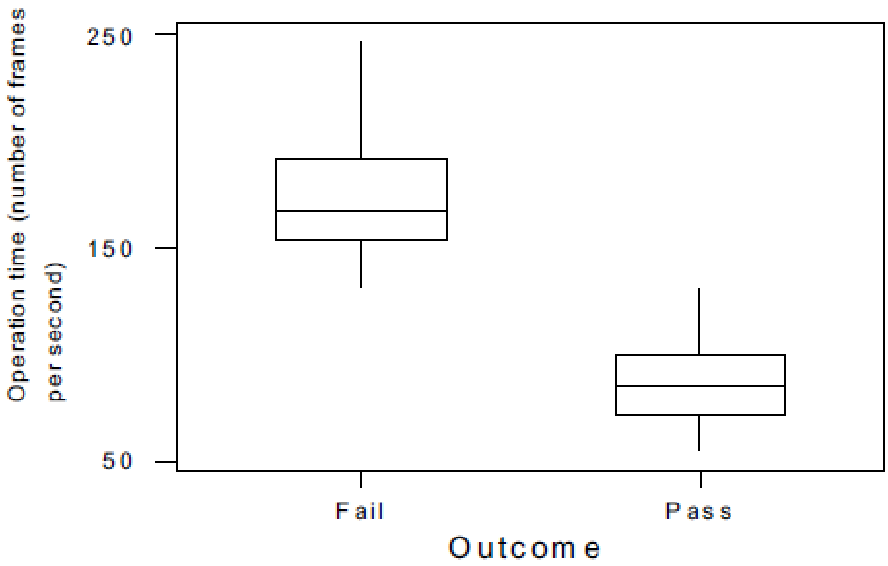

Figure 4.4. Box Plot for Operation Time

The cut cycle time at successful chop-over was different from the cut cycle time at unsuccessful chop-over so that the team chose the cut cycle time as indicator in the winder operation. However, the measurement system needs to be analyzed to evaluate its potential capability.

Gauge R & R analysis that is conducted to assess whether the change is due to the measurement system. Repeatability and reproducibility are two component of the variation in measurement (Kiemele, 1997 and Pyzdek, 2001). 4.7892 is sigma value of the measurement system in this case. It is formed by a sigma reproducibility of 0.8339 and a sigma repeatability of 4.8612. The sigma total is 27.907, producing a precision to total ratio of 0.1742 (4.81/27.907). Thus, the proposed measuring system shows a relative good measurement system capability.

The team decided to start with the identification causes of the problem, identify the 'X' to measure. Figure 4.5 shows the possible reasons that can cause a failure in the re-winder cutting operation. The team identified the potential causes (X) at brainstorming session.18. Figure 4.5 shows that most of the possible causes are from the re-winder and the type of product. At the enr of this session, totally 21 'X' are defined.

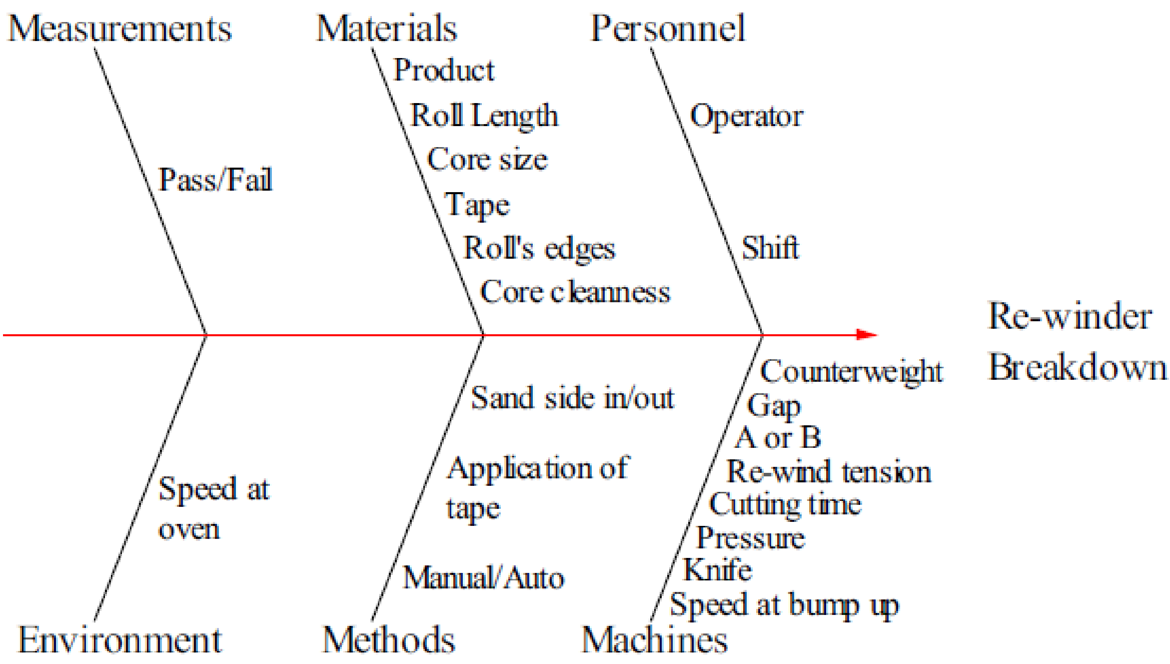

Figure 4.5. Cause and Effect Diagram for re-winder

Team of Six Sigma is aimed at understanding the relationship between changes in downstream factors (‘X’) and their influence on the outcome (‘Y ’).

The data collection plan included the ‘X’ to measure, their operational definitions, identification of data sources and data collection forms (Eckes, 2001). The Six Sigma team focused on distinct groups of project challenges and opportunities as a result of the measure phase.

At the end of the measure phase, the team reached the following:

- The data type and collection technique were identified at data collection plan
- The measurement system was validated to repeatability and reproducibility
- The project direction was determined based on preliminary analysis results
- The current performance was measured with baseline values

The analysis phase aims to understand data in order to generate, segment, prioritize and verify the possible root causes and their relation to the outputs. The inputs of analysis phase are collected from measure phase. Since the collection of data over a relatively long period is executed, it showed full-range variation on a long-term basis.

The Six Sigma team used different tools and technique to understand the dependence between the input "X" and output "Y". Main effects plots were employed to log data means for different "X". The points in the plot represent the means of the response variable at various levels of each ‘X’, with a reference line drawn at the grand mean of the response data (cut cycle time) (Antony, 2003). They were used for comparing magnitudes of the different "X" on the reaction. These are the result but the result of the data collection not the result of a design of experiment.

The effects of five different 'X' plot at different levels and their influence in cut cycle time. Figure 4.6 approved a major factor in the performance of cutting time is the unit where the cut operation is performed. The results show that performance of the top unit (8.53% defect rate) better than performance on the bottom unit (10.55% defect rate). Study has shown that the difference in cut operational time between the bump and cut cycle on the bottom can be attributed to a possible difference in the pneumatic system in both units, the top unit having more recent pneumatic controls. As the result, the pneumatic system was upgraded by the team at the bottom unit. The bump delay was eliminated and failure rate decreased after the replacement. Besides, failures still occurred this means more than one "X" generated failures.

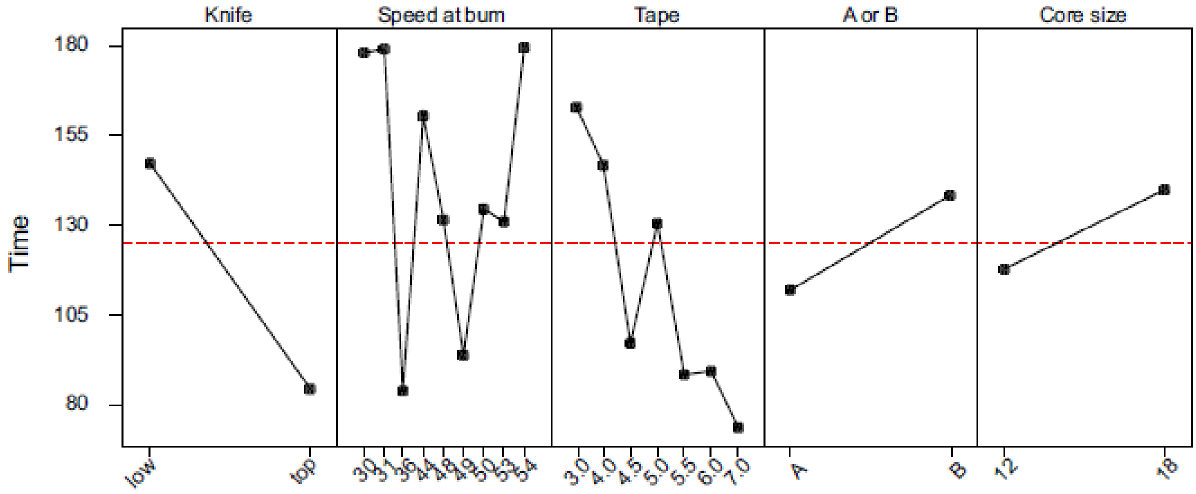

Figure 4.6. Main Effects Plot—Data Means for Time

Figure 4.7 shows a multi-vari chart which is helped to understand the correlation between the spindle and the base size of the gap. Multi-vari studies are useful in obtaining and understanding the process during its natural variation. The process performance is seen Figure 4.7 under two scenarios which are the change gap variation is less than one standard deviation or more than one standard deviation. The cutting operation time is better at the change gap variation is less than one standard.

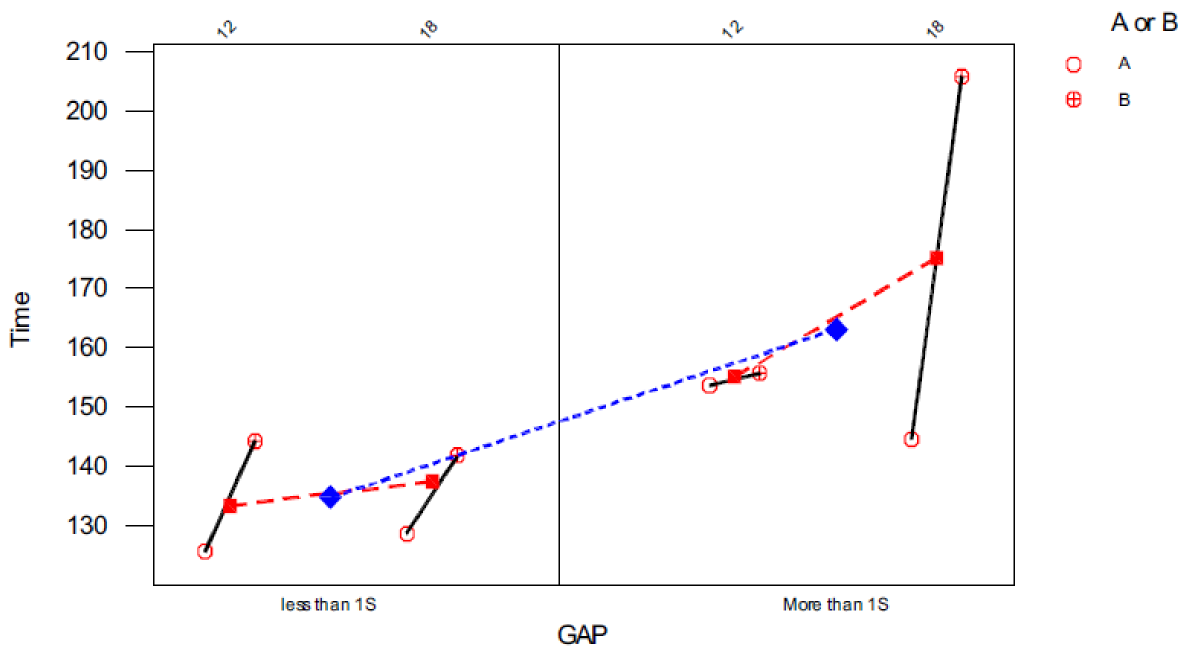

Figure 4.7. Multi-vari Chart for Time by A or B Gap Core Size

The team analyzed the main effects plots and the multi-veri chart, after that they decided to focus on the gap between the new primary focus (prime position) and a knife. The stop positon determined the gap which would be critical to the re-winder performance. The knife reaches the new core before the web is cut when the gap is too small. The opposite of this, when the gap is too large, the knife cut properly but pack arm fails to press the Web onto the new core and the Web moves from the core. As the result of Figure 4.7, the limit switch system makes the re-winder turret stop in a specific position depending on the unit, spindle and core size. The critical 'X' is the gap variable for the system.

The end of the data collection plan and analyzing the data with gauge R&R, basic descriptive statistics and main effects plot. After the analyzing the data some 'X' were selected for further analysis (gap, core size, spindle, unit/knife). As a result of the analysis phase, the Six Sigma team members understand which factors impact to project, including:

- Sources of variation was identified
- The team identified key process input variables

This phase aims selecting solutions to reduce failure and improve the objective which is found in analysis phase. The team analyzed the multi-vari study and they understood the connection of different factors and finally the team found the source of variation which is the gap factor.

The multi-vari study showed to the team that the gap, which is between the re-winder's pack arm and the new core, influences to result. The probability of system failure was identified with statistical tolerance of the gap based on change of the actual parts. The main goal was to identify the sources of variation in the gap position and possible ways to eliminate it form process.

The samples were taken including all possible combinations between core sizes (12" and 18"), spindles (A and B) and re-winder's units (top and bottom) in order to create acceptance range. As a result, the minimum gap size is 0.350 inch and the maximum gap size is 1.200 inch to work properly. These are upper and lower limits of the CTQ characteristic, after that the Six Sigma level helped to the team to predict process capability in the short term and long term. 'Rational Subgrouping' was used to separate sigma short term and sigma long term as recommended by Eckvall and Juran and used by Harry to calculate the 1.5 shift (Eckvall & Juran, 1974 and Harry, 1994). The Ishikawa tree and the multi-vari study showed the different core sizes and spindles affect the gap so that the spindle combinations (A or B), and the core sizes (12 ', 18' ') were selected to subgroups. The variation within subgroups or streams was calculated to get the sigma short term. The results are shown in Table 4.2.

Table 4.2. ANOVA Table

Source of variation	SS	df	MS	$MS^{1/2}$	F	p-value	F_{crit}
Between operators	2.05050	3	0.68350	0.82674	47.1126	1.51E-12	2.866265
Within operator	0.52228	36	0.01451	0.12045			
Total	2.57278	39					

Sigma short term is calculated from the data. Sigma short term assumes each subgroup average is center so all subgroup means are artificially centered to a target value in this case and the sigma short term level is 3.52. After this calculation, the sigma level long term is calculated and 1.4701 is the sigma level long term based on data. The difference between the short-time and long-sigma level is sigma shift which identify how well the process being measured is controlled over time. The sigma shift is 2.0499.

The assumption based on the literature (Pyzdek, 2001 and Harry, 1994) of 1.5 sigma shift, the calculated sigma shift was not appropriate.

Three different factors, which are (T1), the variability of the turret to reach the bump position; (C2), the variability in core size; and (A3), the variability of the bump unit or pack arm to reach the bump position, effect the gap. As shown in Figure 4.8;

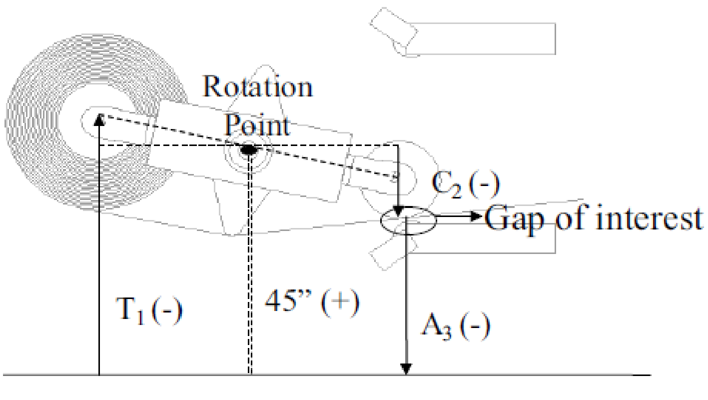

Figure 4.8. Vector Diagram

The connection of several components (T1, C2, and A3) is shown at vector diagram. As a result, an increase in any of the component dimensions decreases the gap. μ_{gap} and σ_{gap} define the transfer function of the subsystem CTQ 'gap' statistically. The means and standard deviations of the part dimensions are used for these calculations. The following equation gives the re-winder's gap, based on vector diagram.

$$\mu_{\text{gap}} = 45 - (\mu_{\text{T1}} - 45) - \left(\frac{\mu_{\text{C2}}}{2} + \mu_{\text{A3}}\right)$$

which is affected by its respective variation given by

$$\sigma^2_{\text{gap}} = \sigma^2_{\text{T1}} + \left(\frac{\sigma^2_{\text{C2}}}{2}\right) + \sigma^2_{\text{A3}}$$

The means and standard deviations for all the parts were calculated and given in Table 4.3.

Table 4.3. Parts' Statistical Description

	Parts σ	Mean	σ	σ	Contribution to σ (%)
T1	Bottom/12"/A	51.8841	0.1579	0.0249	88.51
	Bottom/18"/A	48.6611	0.0595	0.0035	74.38
	Bottom/12"/B	51.4850	0.0722	0.0052	77.89
	Bottom/18"/B	48.2638	0.0854	0.0073	80.64
C2	Core (12")	12.1040	0.0292	0.0009	12.78
	Core (18")	18.1170	0.0292	0.0009	12.78
A3	Arm	31.5480	0.0059	0.0000	5.16

Therefore from Equations μ_{gap} and σ_{gap} the resultant gaps are:

Gap in bottom/12"/A	0.5159	0.1784
Gap in bottom/18"/A	0.7324	0.0800
Gap in bottom/12"/B	0.9150	0.1059
Gap in bottom/18"/B	1.1297	0.1059
Average gap	0.8233	0.1143

As result of the Table 6, between 74% and 88% of the variation occurs from the turret (T1) factor and the turret's mean differs depending on the core size (12 or 18) and spindle (A or B). In this study, the longest cutting operation occurs the combination of core size 18" and B turret. This is followed by B–12", A–18" and finally A–12". All of this shows the turret part (T1) is the main source of variability. The current limit switch system is not capable of satisfying the specification limits. The improved solution was performed in the control phase.

At the end of the improve phase, the team reached the following:

- The team identified alternative improvement for the process.
- The best improvement alternative was applied to the process.
- The improvement was validated by the team.

Six Sigma team passed to control phase after identifying the cause of the problem and possible solutions to reduce process variation. The control phase aims to preserve the implementation of existing measures and actions to improve monitoring, standardization, documentation, and integration of the new method on a daily basis (Pande & Neuman, 2000).

The solution involves the improvement of the gap by providing the operators with a feedback system which allows them to understand the optimal position of turret and to move turret in this position. The proposed solution consists of installing spirit levels in the extreme of the turret to measure the angle and therefore the gap between the turret and the arm. Thus, the gap is arranged by the operator according to the water bubble until the bubble is centered. The operator monitored the water level from the machine control with the camera. The turret has 12 levels which are the combinations of core sizes (10", 12" and 18"), units (top and bottom) and spindles (A and B), which produce different gaps.

The ability of this improvement was determined by measuring the length of the operator resets the gap corresponding to the level of water. After the improvement, the standard deviation (long term) of the spindle variability is reduced from 0.2568 to 0.074 and Table 4.4 shows a gap system's sigma level is 2.03.

Table 4.4. Final Capability

	Before	Improve spring levels
DPMO	115070	21311
First pass yield	88.50%	97.87%
Defect ratio	11.50%	2.13%
COPQ (annual)	£58080	£10763
Total savings (annual)	—	£47317
σ long term	1.2	2.03

The control plan aims to operate sustained solutions with minimum variation. It also helps to identify and implement process improvements to be institutionalized through appropriate training in all procedures.

Control plan, which shows specifications limits, the target values and standard deviation expected for this critical to quality characteristic, was adopted. Control plan, which is designed by Six Sigma team, includes a standard operating procedure (SOP) with response plan. The SOP paper describes how to perform the operation utilizing the spirit levels. Besides, when the system has failure, it describes the response plan by explaining how to redispose the spirit level. The proposed solution is considered by itself a mistake proofing solution, because it reduces the ambiguity of the operator criterion of deciding using the naked eye what is the optimal gap. The Six Sigma team institutionalized the improved process and its ongoing performance was monitored.

In today organizations, many company use Six Sigma methodology to improve performance. In this case study, the Six Sigma DMAIC methodology is used to reduce waste in a continuous film line.

As a result, at the short period the company had significant financial benefits such as reduce waste by almost 50000 £ per year. Result of reduce waste, runtime was increased and quality was improved. On the other hand, workers which are participant to Six Sigma project learnt to solve problem with application of statistical thinking. When people saw payback form the project, they want to practice more Six Sigma projects at the company.

4.1.2. Ford Team Project Builds Relationships, Improves Quality

The Ford Motor Company, founded in 1903, designs, develops, manufactures and services cars and trucks across six continents under the Ford and Lincoln brand names. The company also performs products and services in the areas of maintenance, clash, accessories of automobiles, and widened service warranties under the Genuine Ford Parts, Ford Custom Accessories, and Motorcraft brand names. The organization, which is based in Dearborn, Michigan, employs more than 166,000 people and operates 70 plants worldwide (Jacobsen, 2011).

Ford fiesta is introduced that is the most significant vehicle in Ford Motor Company's recent history while continuing to increase gas prices in early 2010. Performance of customer satisfaction and Ford's warranty are affirmed that impeccable lunch (Jacobsen, 2011).

The problem is determined about the quality of the Fiesta's carpet floor in early tests. Although making repeatedly test to solve, Ford and carpet manufacturer which is a valued supplier, were not able to found a solution. It was not only problem about quality of the Fiesta but also relationship between Ford and supplier (Jacobsen, 2011).

The carpet supplier for the Fiesta is HP Pelzer Automotive Systems, which is a first worldwide supplier of automotive interior trim and components. North American headquarters of company are in Troy, Michigan and carpet manufacturing plant for Fiesta is located in Eudora, Kan (Jacobsen, 2011).

As soon as Ford Fiesta arrives at franchise, the reviews of pre-launching are focused on a concern which is about visible brush marks on vehicle's carpet. Simply, customers are dissatisfied with the appearance of the carpet. Generally, warranty and data of the customer satisfaction are used to define top priority project by Ford. Due to the fact that Fiesta is a new product, Ford banked on projected warranty and customer satisfaction impression learning against historical assessments. Addressing the quality of the carpet before manufacturing became appease customer concerns and prevent warranty costs. On the other hand, the quality of carpet was stress relationship between Ford and HP Pelzer, both of the organizations work on the issue too much to achieve product appearance standards and specifications. The stretched relationship is risked goals and strategies of the Ford corporate. Working together like a team and improving technical superiority to report results are the One Ford Plan. The disruption of the relationship between Ford and HP Pelzer jeopardized elements of the One

Ford Plan, shown in Table 4.5. Accusation, blaming, not acting in concert to solve problem and share data, exerciser nonproductive studies are not improved technical excellence and helped report results (Jacobsen, 2011).

Table 4.5. Risk and Impact of The Carpet Quality Issue, Quantified Using a 10-point Scale, on Ford's Corporate Goals and Strategies

Organizational goal/strategy	Risk of not delivering X	Magnitude of impact=	Measure of severity
One team/One plan	8	9	72
Foster technical excellence	6	7	42
Own working together	8	8	64
Deliver results	10	9	90

According as a requirement for analytical expertise, Ford's Body Six Sigma team alias a group of Six Sigma Black Belts was assigned to lead this important project in March 2010. Following representatives from Ford and HP Pelzer are contained the improvement team (Jacobsen, 2011):

- Scott Sterbenz, Ford Body Engineering, Six Sigma Master Black Belt, team leader and DMAIC expert
- Pramod Thanedar, Ford Body Engineering, Six Sigma Black Belt
- Gary Danhoff, Ford Body Engineering, Six Sigma Black Belt
- Wendy Pinter, Ford Body Engineering supervisor
- Jane Aselage, Ford Global Car Programs, Trim Manager
- Jan Ladewing, HP Pelzer, Research and Development Director
- Tom Hanners, HP Pelzer, Plant Manager
- Ryan Yamnits, HP Pelzer, Process Engineer
- Kurt Mueller, HP Pelzer, Quality Manager
- Steve VanHeusden, HP Pelzer, Ford Program Manager

Representatives were selected depends on their areas of expertise and the responsibilities defined inside the project. Every person who is participated was based on the requirements for an especial stage of the project, which contained define, measure, analyze, improve and control (DMAIC) methodology of the Six Sigma (Jacobsen, 2011).

After identifying the scope of project, one of the first assignments was preparing a supplier, inputs, process, outputs, and customers (SIPOC) diagram to identify stakeholders. External stakeholders contained HP Pelzer, and the end customer namely future owners of the Fiesta. On the other hand, internal stakeholders contained the Fiesta program team, the Fiesta assembly plant (Cuautitlan, Mexico), and the Body Six Sigma team members. The raw materials suppliers wasn’t contained external stakeholders because data pointed that raw materials variation and quality weren’t quality root causes (Jacobsen, 2011).

Six Sigma Master Black Belt and team leader, Scott Sterbenz explains in the first meeting with members of the team, the automotive carpet manufacturing process, shown in Figure 4.9, should be focused by the improvement team. Sterbenz says “We are big believers in knowing how things work. After all, if you can’t explain how something works, how can you possibly explain how it doesn’t?”.

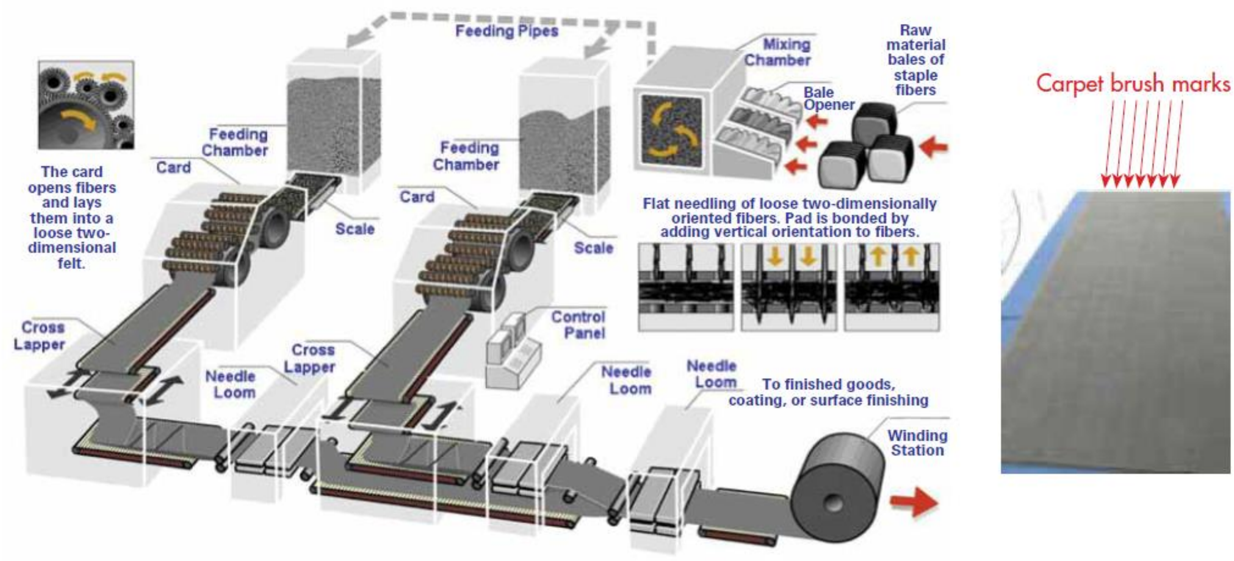

Figure 4.9. Carpet Manufacturing Process

A fishbone diagram and f(x) cascade were created by the team, after discussing the present process with HP Pelzer’s engineers who are an expert on carpet area. The y=f(x) cascade, which is a physics and engineering based flowchart, is used to define potential root causes by way of why and how questions. Until especial measurable are defined, these questions are asked repeatedly. It is important to identify these measures because of determining the key process input variables (KPIVs). In analyze phase, these measures were transformed KPIVs. After that, control of these KPIVs instinctively turns into control of the key process output variables (KPOVs). In the y=f(x) equation, the big Y means KPOVs. At this stage; by the way of the y=f(x) cascade, the improvement team thought to focused on the needler machine. The needler has a place for needles which penetrate the raw materials to manufacture carpet pile. The needler and automatically the needler settings came in possession of determinant in the design of experiments (DOE). The KPIVs were identified substantially by the way of settings of the certain needler in the DOE. Sterbenz explains that the KPIVs and consequently control the big Y, which means the parameters of carpet quality, were able to be controlled by the team at the end of the project. (Jacobsen, 2011).

He says that it was understood clearly from the beginning the needler was significant point to the whole quality of the carpet. Luckily, there were a limited number of settings in the needler. This situation was useful to submit an ideal solution for using DOE. It is important to find ideal solution to optimize the process and analyze root causes. Despite of the fact that the needler settings had been changed in previous studies by HP Pelzer, Ford's Black Belts indicated that making some test by the way of changing one factor at a time hadn't been done scientifically (Jacobsen, 2011).

After the DOE planning was complete, the members of Ford team went to HP Pelzer's plant (Eudora, Kan) where the team analyzed produced samples of the carpet when the settings of the needler were changed. The team realized instantly that some of the carpets were pretty comfortable but the others made feel unpleasant texture. Herein, the team made a decision that both of these features which are brush marking and softness/plushness would be processed like as interference in the DOE (Jacobsen, 2011).

Following, the team assembled an assessment jury composed of Ford and HP Pelzer representatives to perform a gauge repeatability and reproducibility (R&R) work on the two responses. By the way of using an ordinal ranking scale (1-10 used for brush marking, 1-5 used for softness/plushness), softness/plushness and brush markings were graded. The better quality was represented by the higher rating. Next, all responses were featured and sequential in nature, Kendall's Co-efficient of Concordance was performed like as the indicator of success. This formula evaluates directional agreement with a value of higher than 0.7 for both responses, showing that for evaluating the carpets properly and regularly the jury was trustable. Moreover, the team knew that variation in the jury's opinion weren't shifted in the rankings, but instead from current quality impact resulting from the modified to settings of the needler (Jacobsen, 2011).

In spite of attentive planning, some unforeseen troubles were experienced during the DOE by the team. Three hours to finish were spent by the first four times. Sterbenz reports regulating the experiment was elementally the biggest bottleneck just because process of manufacturing is complicated and uses a continuous roll of material. Performing each DOE run combination on individual rolls would have been wasteful. Because of that, changing settings of the machine instantly and signing the roll where indicated changes were the only alternative. There should be needed excellent coordination and more workforce than originally expected. Sterbenz says "It took us a few hours and a few botched runs to work out the logistic, but we got it. This created some stressful moments where I thought the DOE would be abandoned, but through teamwork and some quick problem solving, we succeeded".

Pareto chart, an analysis of variance Table, and plots of the interactions and main effects were used to analyze the DOE. If researching the information from the brush marks, using unsystematically adjusting the settings of needler by HP Pelzer would be more understandable to succeed the specified quality. There were two important three-way interactions and several important two-way interactions. There were only two important effects for softness/plushness because of that it was less complex. This eased the process of concurrently optimizing two responses (Jacobsen, 2011).

Sterbenz clarify that a list of significant variables and interactions and a transfer function between the inputs and the response were provided by the DOE. The mathematical and physics relationship between the KPIV and the KPOV represents the transfer functions. At this stage, the mathematical relationship between the needler's settings which means KPIV and the quality of the carpet which means KPOV represents the transfer function (Jacobsen, 2011).

The variables that control brush marking and softness/plushness were defined by the team, after using the supplier's knowledge of the process of carpet and research of the DOE. Significant interactions within the variables clearly caused to be unsuccessful in the past settings of the needler adjustments. Mathematical models were equipped for each response, targets were determined by the team, and after validation, by the way of using optimization solvers they uncovered the best settings for brush marks and softness/plushness (Jacobsen, 2011).

When the optimum settings of the needler were found, the analysis of data was shared at a full team meeting. Sadly, these settings were not used because of damaging the needler if used extendedly. In addition, one of the factor settings could influence adversely the durability of carpet. Because of these constraints, additional analysis was required.

In spite of the new constraints, two new optimized factor settings were identified for the needler by the team. The aims of new settings were to ensure substantially higher levels of quality for brush marks and plushness/softness. The following stage was manufacturing samples of all options for the jury to measure. Luckily, there were not any brush markings on the samples and the softness/plushness was much more improved than expected. The ratings of jury -8.2 (out of 10, and both samples had same rating) for brush marking and 3.7 (out of 5 for option one) and 3.8 (out of 5 for option two) on softness/plushness- closely proper the prediction of mathematical model. In the course of events, option two was selected by the team because it manufactured a little more plush carpet. The differences in the carpet quality after DOE is indicated Figure 4.10 (Jacobsen, 2011).

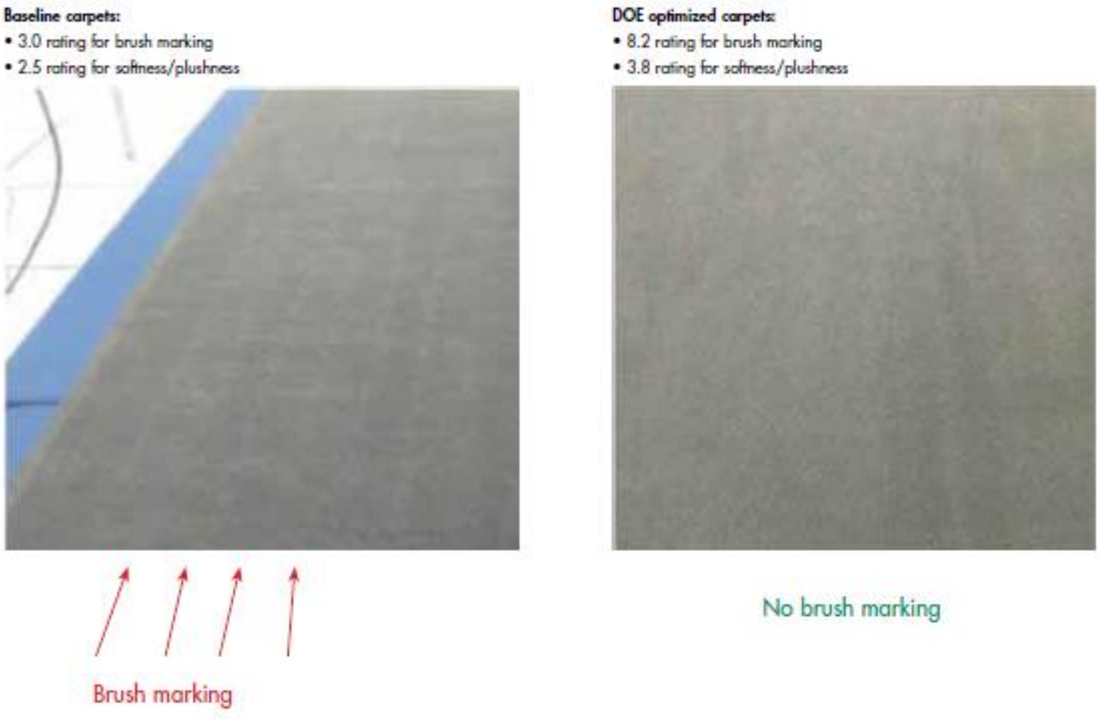

Figure 4.10. Ford Fiesta Carpet Before and After The DOE

The final samples were trialed to make sure that additional factors like as sheen, color, wear, durability, stain resistance, and uniform pile direction were not dangerous. The samples were outcompeted all test of validation (Jacobsen, 2011).

Schedules to practice the final improvement actions swiftly and make the results permanent included following task (Jacobsen, 2011):

- Getting in contact with HP Pelzer employees about the new process.
- Programming the new settings on the needler.
- Observing the produced carpets' quality.
- Observing the needler's condition.

After improving the new Fiesta's carpet, the improvement team wanted to make sure that future model also were conserved. Throughout practicing quality and maintenance control plans; if documenting the gauge R&R methodology and the transfer function development process with the supplier were analyzed, it was understood clearly that the team was made an effort for both current and future models‘ quality. While manufacturing of the Fiesta hadn't begun, Ford and HP Pelzer were gotten valuable benefits from the project which took approximately two weeks for completing, like as avoiding warranty claims, protecting customer satisfaction and reducing scarp materials, shown in Table 4.6.

Table 4.6. Tangible Benefits for Both Ford and The Supplier

Realized Tangible Benefit	Recipient	Value	Validation
Warranty avoidance	Ford	$630 per daim	No warranty claims (mass production started in May 2010)
Scarp avoidance	HP Pelzer	$1,200 per roll	No scrapped carpet rolls (mass production began in April 2010)
Customer satisfaction Loss avoidance	Ford External customer	Proprietary calculation Carpets that look and feel as expected	No customer complaints about carpet quality an either internal or external surveys

Moreover, the intangible benefits were remarkable:

- Enhanced technical excellence.
- A powerful connection with the supplier.
- A flawless product for customer.
- The innovation of a new optimization process for the supplier.
- The innovation of a Six Sigma program by HP Pelzer to enhance efficiency and develop quality.

The aims of One Ford Strategy were succeed unambiguously in this project. Ford's relationship with the supplier was reinforced by the way of teamwork and sharing experience.

Sterbenz explains that the key to the success of this project were understanding clearly the critical KPIVs and structure of the team. "It was surprising to us that scientific experiments had not been conducted prior to this project to fully understand the KPIVs. Now that the KPIVs are understood, we have much better control over the process and understand how to control the sensitivity of the certain factors."

In the implementation phase improvement projects can experience some strength. At this stage, when the DOE was managed and the supplier was worried about potential damage to the needler and potential perverse effects on durability of the carpet some critical questions came earlier. These problems could be solved by training programs and successful examples, by the way of strengthening the statistical expertise of Ford's Six Sigma Black Belts (Jacobsen, 2011).

Ford is an enterprise member of ASQ and knows in the value of sharing quality success process because methods and tools can be used also in another project. In this improvement project the results were shared with other teams at Ford and HP Pelzer and with a larger group by the way of ASQ's International Team Excellence Award (ITEA) process. Team Ford-Body Engineering was one of the finalists in the 2011 ITEA which was consisted of 29 finalists. The process was shared with a live audience by members of the team at the 2011 World Conference on Quality and Improvement, where they ranked the best OEM/supplier relationship award and 2nd award in the team display competition (Jacobsen, 2011).

Sterbenz explains this project was a proper applicant for the ITEA because of reducing defects rate to zero. There haven't been any warranty claims on the carpet after one year. he says "That is total success and the epitome of teambuilding" (Jacobsen, 2011).

4.1.3. Using Six Sigma to Improve Complaints Handling

The selected company, which is a multinational from automotive sector, purposes high standards of quality. Therefore it uses Six Sigma projects in order to improve quality. Raise in capacity of competitive and quality is succeeded in different ways with importance given on the Six Sigma projects. Continual customer complaints were received because of the deadline breach in the process of faulty products analysis and the high waiting time to be analyzed the product. Therefore Six Sigma project was selected to be focused on the issue. Normally, this project is not a Six Sigma project because of that the customer complaints handling process is not a main production process highly repetitive and stable. Six Sigma, which is structured and organized improvement methodology, is used some statistical techniques and tools in order to decrease variability and waste of processes. The project team chose the DMAIC methodology because of the commitment of the company's board of directors and the project team. Formal mechanisms are used for this type of projects in order to evaluate and control project implementation (Abreu, Sousa, Lopes, 2012).

Returned products from customers are analyzed in the laboratory. After analysis, faulty products are distributed into two groups by the way of origin of complaints: 0 km complaints which are failures and field failure. 0 km failures are determined in plants of customers and after the car sale and along warranty period, the end of customers determines the field failure. Determined defect means the nonperformance of the deadline for device analysis. Devices which resulted from a 0 km complaint should be researched in less than 2 days and devices which resulted from field failure should be researched also in less than 15 days. If not so the analysis process is been defective (Abreu, Sousa, Lopes, 2012).

The improvement of customer service raise in productivity of laboratory, the improvement in quality tools pertained to 0 km and field devices, standardization of the process of laboratory analysis and reduction in the volume of equipment waiting time to be researched were hoped like as benefits with the realization of the Six Sigma project (Abreu, Sousa, Lopes, 2012).

A project charter which was created to define the project, shown in Figure 4.11, was used with flowchart and turtle diagram to clearly show the process and its inputs and outputs.

Case study	**Declaration of Opportunity**
In recent years the company has seen a decrease in customer satisfaction in relation to complaints response time and thus selected a Six Sigma project to improve the process of analysis of defective products.	Reduction of the defects analysis time and variability.
Defect Definition: Failure to comply with the time of analysis (2 days for 0km claims and 15 days for field claims).	
Objective	**Project Scope:**
Identify the variables that influence the process of analysis; propose improvements to reduce the analysis time and the related variability in order to meet the deadline of delivery.	Start Date: April 1, 2011 End date: October 14, 2011
Benefits: Increase the laboratory productivity, improve customer service; improve 0km and field quality indicators; standardize the process of analysis and reduce the number of products without analysis.	Scope: Analysis of 0km and field defects Outside of the scope: Analysis of defects FOR

Project Plan:			**Team:**		
phase	**start**	**end**	**name**	**role**	**commitment**
Define	April	May	Patrícia Abreu	Leader	high
Measure	May	June	Natália Semanas	Black Belt	medium
Analyse	June	July	João Roque	Black Belt	medium
Improve	July	September	Miguel Soares	Sponsor	low
Control	August	October	Fernando Barbosa	Project Team	low
			Nuno Iglésias		low
			Tec. QMM1 Lab		low

Figure 4.11. Project Charter (Abreu, Sousa, Lopes, 2012)

Collected data which is about the analysis of customer complaints respect deadline and customer satisfaction were used in order to percept fully present state of the process. By the way of analysis, the process was found in a critical state and devices were researched tardily in other words the process were been defective, shown in Table 4.7. In the laboratory, two types of devices which are car-radios (CR) and navigation systems (DI) are researched (Abreu, Sousa, Lopes, 2012).

Table 4.7. Percentage of Defective Products (Abreu, Sousa, Lopes, 2012)

Product Type	Origin	%Defectives
CR	0km	75,0%
	Field	55,6%
DI	0km	79,3%
	Field	52,3%

At the stage, the deadline of the device analysis for 0 km complaints was 2 days, but the real analysis time was 7 days for CR and 10 days for DI. On the other hand, the deadline of the device analysis for field complaints was 15 days, but the real analysis time was 21 days for CR and 22 days for DI. The collected data was provided in order to find the average analysis time which was high beside agreed deadline with customers and variability is also high in the analysis time. In Table 2, the four situations were showed in order to calculate the sigma level. The sigma level of whole process was 1.08. This means that there was a big difference between current process and other typical stabilized and repetitive company processes (Abreu, Sousa, Lopes, 2012).

Surveys were made in order to percept overall opinion of their customers every two years.

The company had purposed a level of customer satisfaction which was 3.25 on a scale of 0 to 4 in 2010. On the scale “0” means full dissatisfaction and “4” means full satisfaction.

By the way of analysis of last year, the company was realized that all clients’ satisfaction level about response time of complaints was much less than expected the aim of company (Abreu, Sousa, Lopes, 2012).

Involved people in the project team who were sponsors, project team and coordinator of the laboratory brainstormed in order to create opinion about potential causes which affect the long analysis time (Abreu, Sousa, Lopes, 2012).

After that, the determined causes were also added to the previously defined causes which were collected by the way of observation, the researcher’s interviews of technicians and facts observations. In addition a mind map was enhanced in order to divide the causes into four groups: delays, resident engineer, travel and laboratory (equipment and technicians), shown in Figure 4.12 (Abreu, Sousa, Lopes, 2012).

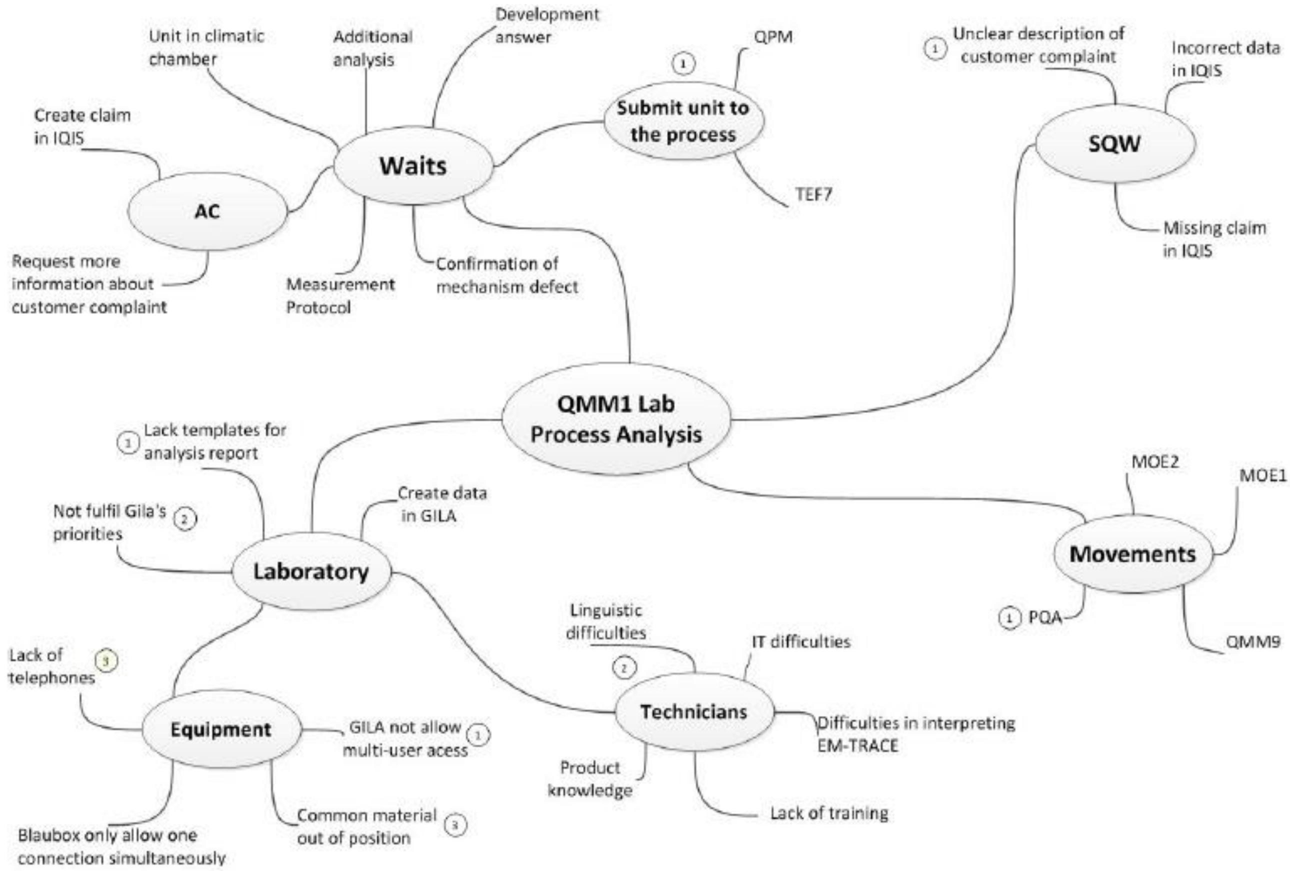

Figure 4.12. Mind Map

In mind map, the problem is settled in the center and is connected with four groups of causes. The actions also were enumerated in order to define the priorities as to a color code. The number one with the red circle means a high priority, the number two with the blue circle means a medium priority and the number 3 with the yellow circle means a low priority (Abreu, Sousa, Lopes, 2012).

Only defined causes about, which there was more information and a realized improvement opportunity, were evaluated the situation like as priorities because of project constraints (Abreu, Sousa, Lopes, 2012).

After the definition of the problem causes, improvements which are to increase the performance of analysis process have been suggested, these suggestions are showed in Table 4.8 (Abreu, Sousa, Lopes, 2012).

Table 4.8. Problem and Actions to be Implemented

Priority	Type	Problem	Action
1	Movements	Movements to the department of defective product analysis (PQA)	Creating a milk run between QMMI Lab and PQA
1	Resident Engineer (SQW)	Unclear description of the defect	Training for SQW mandatory checklist
1	Waiting	Submission of devices to the process	Only devices of corporate responsibility will be submitted
1		Lack of template for the analysis report	Creating a template
1		SAP does not allow multi-user access	
2		Lack of launch of the device in SAP	Change in SAP operation
2		Infringement of priorities in SAP	
2	Laboratory	Technicians	Training in foreign languages, information technology, new equipment and software
3		Commonly used materials outside the place	Creating areas for placement of commonly used materials
3		Lack of telephones	Placing a phone on each bench

These suggestions purposed to procure improvement solutions for the root causes of the problem. The development of milk run in order to decrease trips to the PQA, creation of a checklist to be used by SQW in order to standardize and improve the identification of defect and offer the devices of responsibility B to the process of production were the proposed improvements. Some improvements were also proposed including technicians and equipment at the level of laboratory which is the place of analyses. On the other hand, some of the improvement actions need various changes to the information system of the company and more time to be implemented, because of that they are not yet implemented (Abreu, Sousa, Lopes, 2012).

The performance of process was evaluated after implementation of the improvements in order to determine the effect and affirm the effectiveness of the improvements, as shown in Figure 4.13 and Figure 4.14 (Abreu, Sousa, Lopes, 2012).

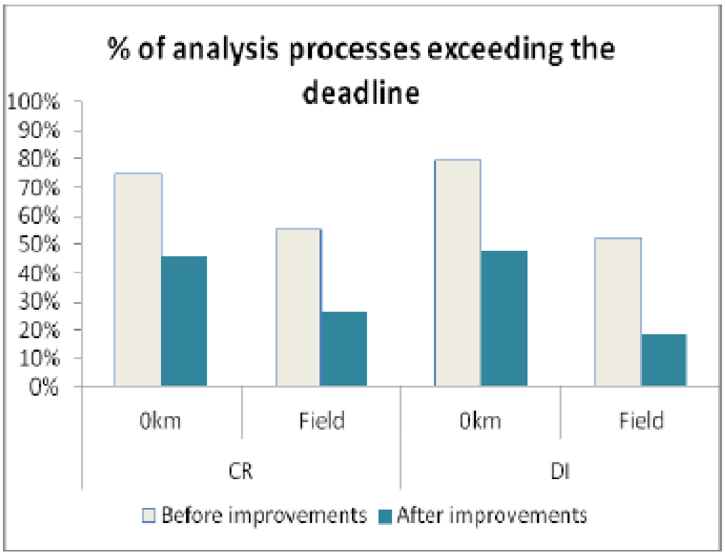

Figure 4.13. Percentage of The Analysis Processes Exceeding The Deadline

If initial data and gathered data after improvements implementation were measured, it is shown clearly that the number of analyzed devices which were not passed the deadline pretty reduced. Accordingly the average analysis time was decreased, as shown in Figure 4.14 (Abreu, Sousa, Lopes, 2012).

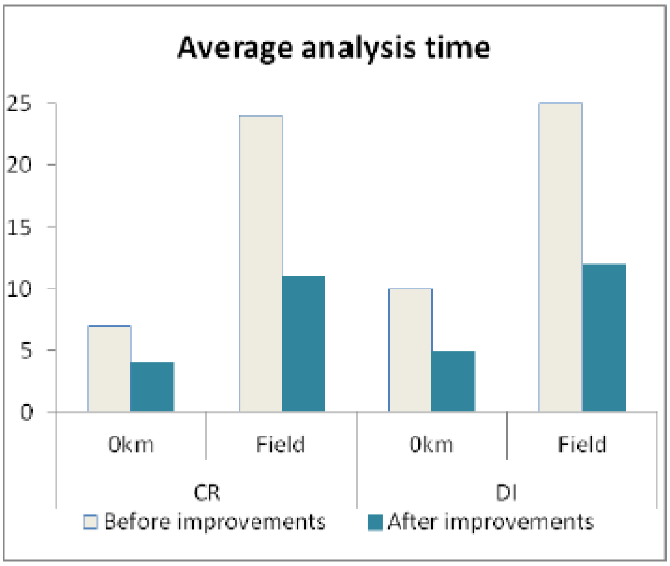

Figure 4.14. Average Analysis Time

The analysis mean time for 0 km devices exchanged from 7 to 4 days respecting CR and exchanged from 10 to 5 days respecting DI. Similarly, the analysis mean time for field devices exchanged from 24 to 11 days respecting CR and exchanged from 25 to 12 days respecting DI (Abreu, Sousa, Lopes, 2012).

There was also reduction of variability. The standard deviation for 0 km devices exchanged from 9.41 to 2.72 concerning CR and exchanged from 10.79 to 3.36 concerning DI. Accordingly, the standard deviation for field devices exchanged from 16.74 to 6.16 concerning CR and exchanged from 23.49 to 5.43 concerning DI (Abreu, Sousa, Lopes, 2012).

Even though there was remarkable decreasing in the analysis mean time and variability, the reduction of average time was 49.8% and the reduction of standard deviation was 71.2%. The analysis mean time couldn’t be reached the target, in two days, for 0 km devices. On the other hand, the analysis mean time could be reached the target, in 15 days, for field devices (Abreu, Sousa, Lopes, 2012).

Despite of that all of the improvements were not yet implemented, the sigma level was increased from 1.08 to 1.92 (Abreu, Sousa, Lopes, 2012).

The reduction of analysis average and variability time, customer requests and the number of technicians affected the defects which are not fulfilled in the determined deadlines. The succeed improvements did not consist of the increase in the number of technicians. The succeed variability reduction will develop a better work planning. In this way if the volume of request enhance over the capacity of process defects can be expected and prevented (Abreu, Sousa, Lopes, 2012).

By the way of these benefits, the project implementation provided to increase productivity, made standardizing the analysis process possible, developed customer service and quality (Abreu, Sousa, Lopes, 2012).

4.1.4. Delivering Record Products without Delays

Music Co. is one of the record label companies. The company's sales team reported customer complaints which were delays of the record products. The company created a team to help deliver record on time. At beginning, the company explained some basic words which are using in this industry (Bakthavatchalam and Fallah, 2010).

Recording companies: In this business, the company provides record opportunity to different record labels.

Record labels: The artist sign contract with record label which are doing campaign for their clients.

Planning system: this is a tool which is helping to label company to schedule a release. With digital music, the system also plan to digital releases. Apple iTunes, eMusic, BuyMusic and Rhapsody are some digital service providers which are confirmed by release management. The key factor is timeliness of a release for the customer satisfaction.

In the music industry, all members want their product on the time without error. So that timeliness is a critical-to-quality (CTQ) characteristic of the process. In this project, the company wants to improve cycle time. To evaluate this Six Sigma project, the company created a project qualification checklist as shown in Table 4.9.

Table 4.9. Project Qualification Checklist

Checklist	High	Medium	Low
How important is this project to your customer?	Y		
Is there a Champion who feels that the project is important?	Y		
Is there a Green Belt to assist this project?	Y		
Is the CTQ characteristic measurable?	Y		
Is data available or easily tracked?	Y		
Are the benefits easily measurable?		Y	
Is the process stabilized or under control?	Y		
Is the scope narrow enough to finish in four to six months?	Y		
Is this project considered important within the organization?	Y		
Are there alternative solutions available?		Y	
Total weight	8	2	

The project qualified, and the team used DMAIC methodology to define the causes of the delays in their planning system and develop action.

In the define phase, the supplier, inputs, process, outputs, and customers (SIPOC) diagram was prepared by the project team and it is seen in Figure 4.15.

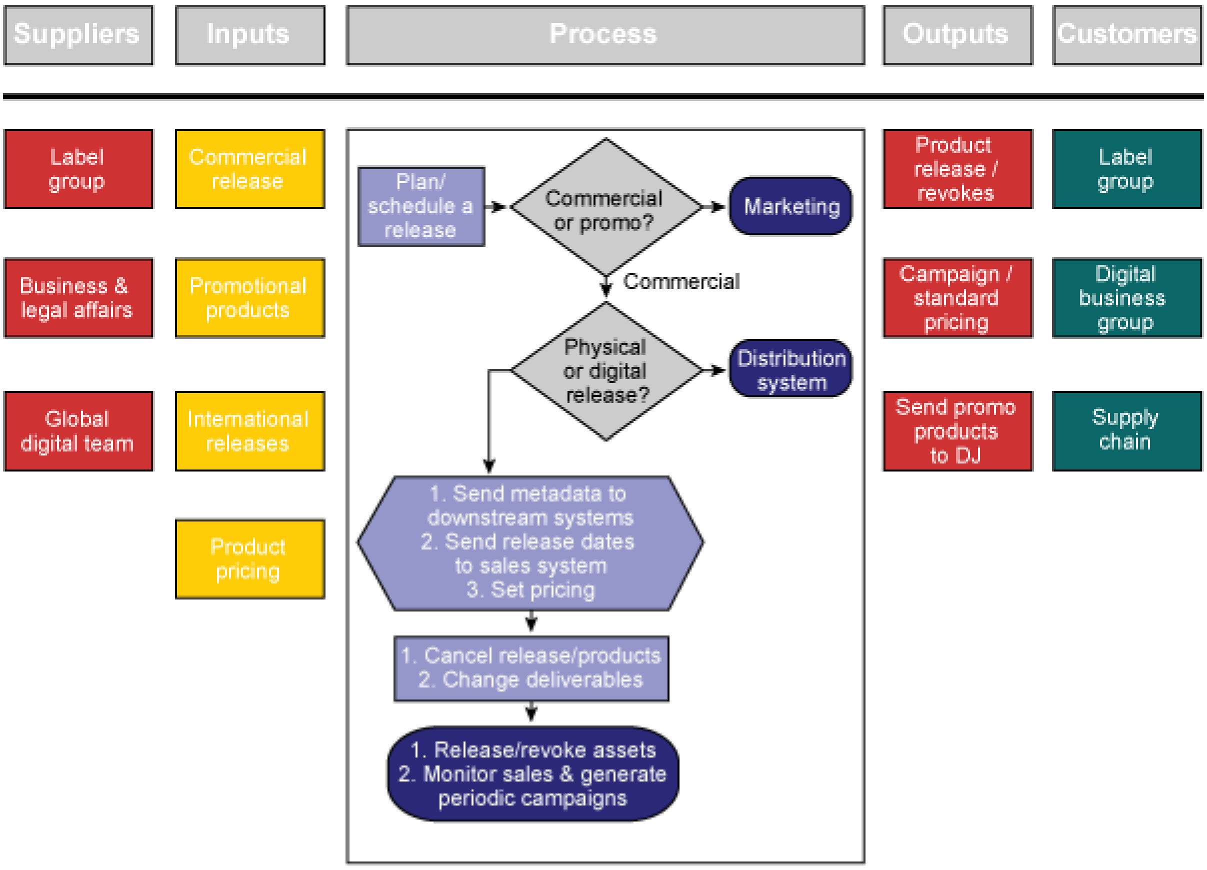

Figure 4.15. SIPOC Diagram of The Label Planning System

When the delivery time of the products is increased, the vendors may get leverage to renegotiate the price. Besides, the future contracts might be canceled by the artist. The consequences of continuing the process is shown in Table 4.10.

Table 4.10. Loss-Gain Matrix

	Loss	Gain
Short Term	-Impact on overall resolution -Related dissatisfaction	-Improved resolution -Related satisfaction
Long Term	-Client escalations -Loss of business	-Client satisfaction -More business -Revenue Growth

The optimal process time, which is from the creation request to the street date, is 14 weeks for the new product. The process steps and timeline are given in Figure 4.16.

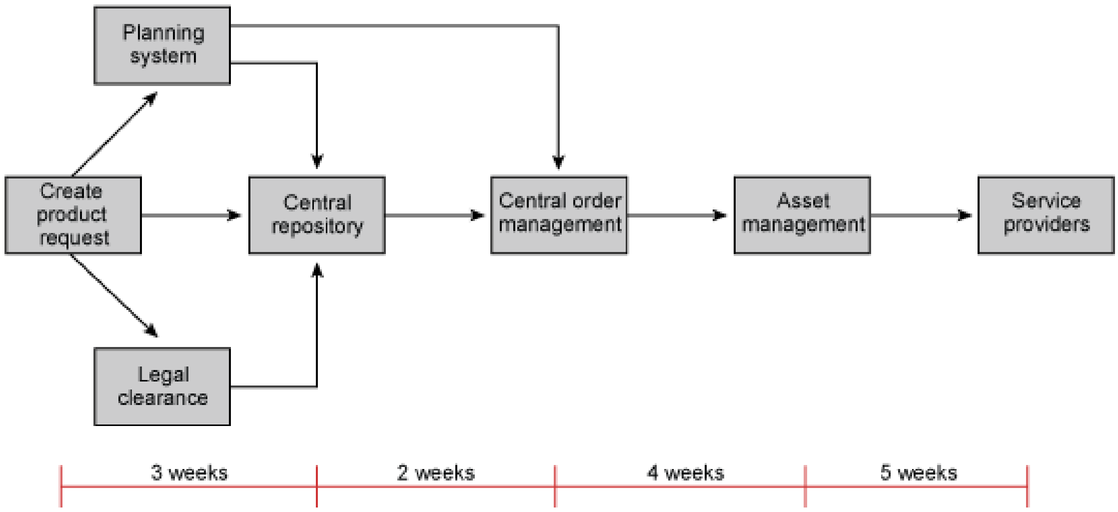

Figure 4.16. Process Map and Life-cycle Timeline

The data, which are from July 2009 to October 2008, are collected from emails, issue tracking tools and request made on the phone. Figure 4.17 shows those data and resolution efforts at this period.

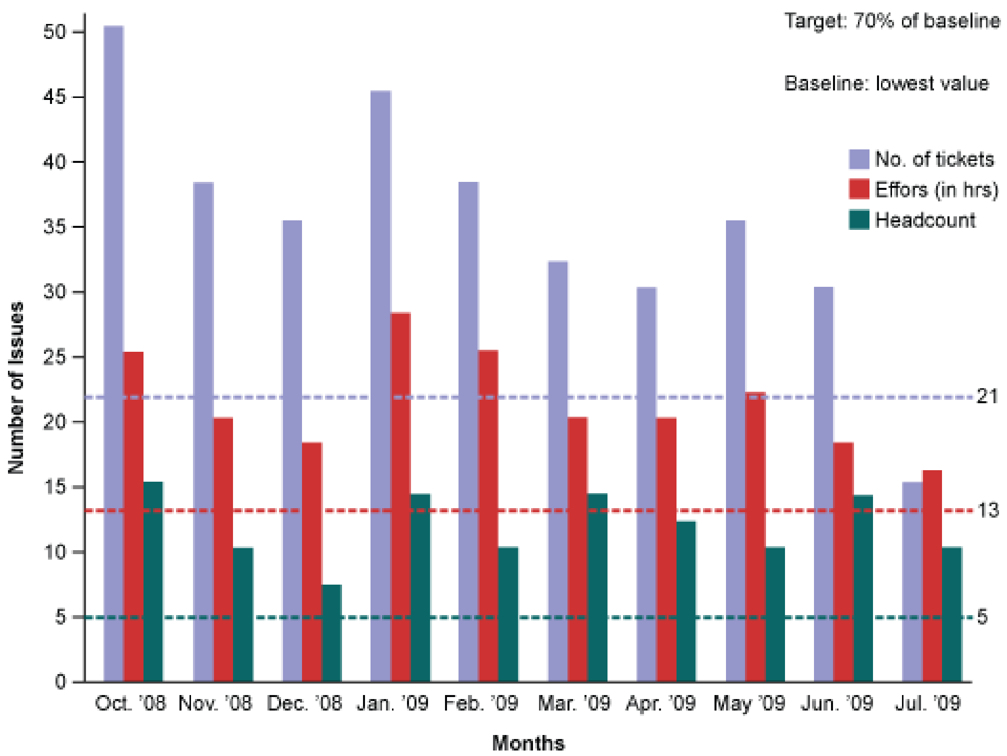

Figure 4.17. Run Chart of Issues and Resolution Efforts from Oct. '08 to Aug. '09

For example; at October 2008, 50 tickets were opened, 15 people worked and each of these spent 25 hours to resolve the issue. The target, which is decided by the project team, is 21tickets per month. When the team calculated sigma level with current process data, the sigma level is 1.78.

The process variation was searched at analyze phase. When the company signs a contract with the artist, the street date of the product is fixed. Therefore the label company must be delivered the new product at contract time to the costumer. Otherwise, the promotion of the product had been delay (Bakthavatchalam and Fallah, 2010).

The aim of the project was significantly reduce Priority 1 (P1) and Priority 2 (P2) tickets. A lot of time and money were spent to these tickets which involve system problems, such as:

- Process follow through
- Software bugs
- Testing efforts (both IT and business)
- Inefficient handling of products due to lack of experience/training

The Ishikawa diagram, which is seen in Figure 4.18.was created for the delays in the process time.

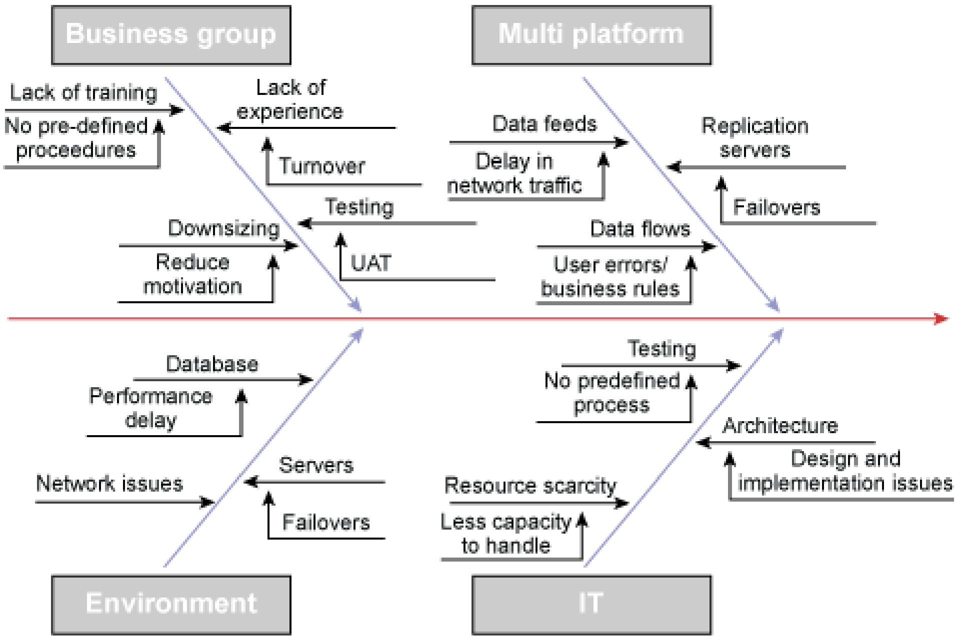

Figure 4.18. Cause-and-Effect Diagram for Delays in Cycle Time

The team focused on four key areas which are business group, multi-platform, environment and IT.

Business group:

- Lack of training: Staff turnover is high so that new employee needs time to understand system.
- Lack of experience due to staff turnover.
- Reduction to staff so that staff motivation is decreased.
- The error noticed at the production stage because of Lack of user acceptance testing.

Multi-platform:

- Data feeds – Delay in network traffic
- Replication servers – They stimulated an unexpected failover when source servers failed
- Data flows – Failure data generated damage in all downstream system.

Planning-system centric environment

- Network issues – Network failures and traffic.
- Server issues – Error in production servers
- Database – Product movement was restricted

Information Systems and Technology:

- Testing – Lack of resource-reducing testing time
- Network issues – Network failures and traffic
- Architecture – Software design issues

End of the many meetings and discussions, the team realized that most of failures were similar. After this result, they categorized issues and monitored the failure numbers in each class. Figure 4.19 present these data.

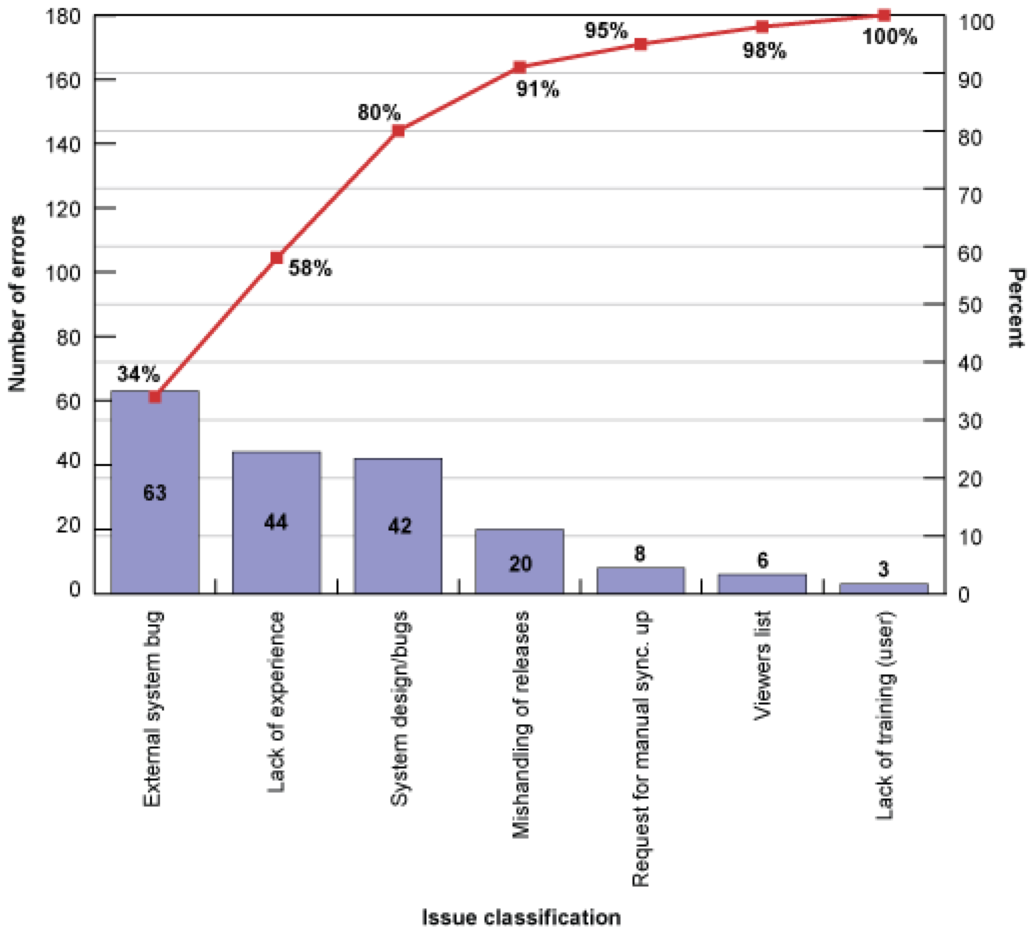

Figure 4.19. Pareto Chart of The Causes of Release Delay

Three categories, which are External system bugs, lack of experience among business groups and system design defects, caused to %80 of delay.

At the improve phase, the team decided to take the actions against to main reasons of the delays. These actions are listed in Table 4.11.

Table 4.11. Action Plan

Action Item No.	Description	Owner	Due Date	Function	Root Causes
1	Meet with Quality Assurance to review current testing plan specific to the planning system	System engineer	Aug. 5, 2009	Release management	Errors/bugs in design of planning system
2	Provide logs of external system bug errors to vendor for evaluation and recommendation	Vendor manager	Aug. 19, 2009	OLA management	Bugs sourced from external systems
3	Test the software fix to the timing feature on the planning system	QA analyst	Aug. 28, 2009	Quality Assurance	
4	Audit and report point-to-point network failures in digital release process	Network administrator	Aug. 28, 2009	Network engineering	
5	Establish training procedures and best practice guidelines for new and existing employees	IT communication manager	Aug. 28, 2009 – review first draft	Service management	Lack of experience, training

The team put the improvement targets which are shown in Figure 4.20. The sigma level of process would be 3.04 after taking the actions.

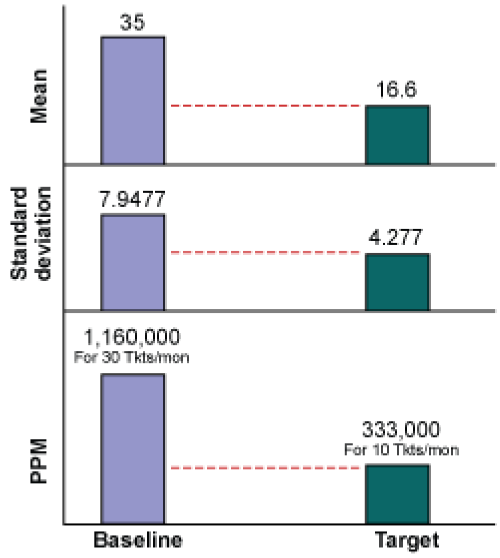

Figure 4.20. Improvement Targets

The team implemented a plan of action and holds the power. The results shows the success of the improvements which is given in Figure 4.21.

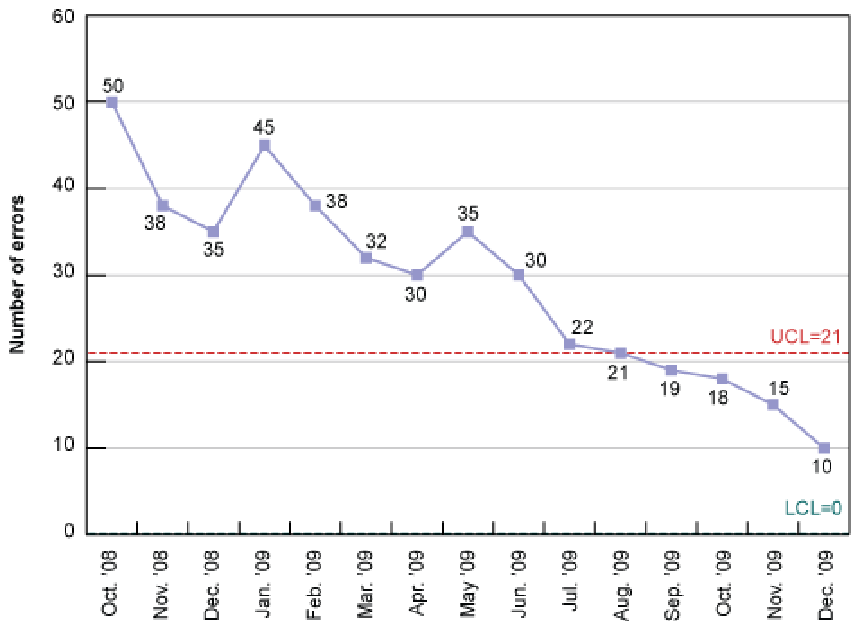

Figure 4.21. Run Chart of The Number of Tickets by Month

The key factor of business improvement is to find out customer requirements. The team used quantitative tools and techniques to find root causes of defects and inefficiencies.

Since this project is important for business records and the results to the record label:

- The company’s revenue is growth more than $2 million per year.

- Downtime is reduced, so that the cycle time decreases to hours from days.
- The company has more knowledge about process, it helps to develop new product.

4.2. Results and Discussion

The application of the techniques and tools to all functions results in improved profitability, a competitive advantage, and a very high level of quality at reduced costs with a reduction in cycle time. It should be emphasized that organizations do not need to use all the measurement units associated with Six Sigma. The most important thing is to choose the best set of measurements for their situation and focus their emphasis on the wise integration of statistical and other improvement tools. Besides that the appropriate application of tools becomes more critical for effectiveness than correctness, and all the tools are not needed to use all the time. The tools, which are used in this case, can be shown in Table 4.12.

Table 4.12. Using Tools

Cases / Tools	1	2	3	4
Project charter	✓	✓	✓	✓
Process map	✓		✓	
SIPOC		✓		✓
Turtle diagram			✓	
Action plan				✓
KPIVs-KPOVs	✓	✓	✓	✓
Pareto chart	✓	✓	✓	✓
Mind map			✓	
Brainstorming	✓		✓	
DOE	✓	✓		
Gauge R&R	✓	✓		
Training stakeholders	✓	✓	✓	✓
Run chart				✓
Transfer function	✓	✓		
Documenting	✓	✓	✓	✓

Six Sigma methodology's aims are increase productivity, improve quality and customer satisfaction. Generally it is used to repetitive and stable process. Some tools are used to qualify projects to implement Six Sigma methodology. For example, project qualification checklist was used in forth case. After this act the project qualified and the team implemented the Six Sigma methodology to the case. In second case, analytical expertise was necessary to solve problem so that the team selected the Six Sigma methodology to apply the case. DMAIC methodology, which is one of the Six Sigma problem solving methodology, was applied to all cases in our study. Define, measure, analyze, improve and control are phases of DMAIC methodology and all this phases are used in the study. Besides that, the Six Sigma belt team was created by the organization. All member of the team has good experience and knowledge about their job. After that the team created the project charter and it helps to identify main problem and limits of the projects.

Various diagrams are used to identify main scope such as in first case. In the case main goal is reduced waste and decreased the cost. When the team created cost tree, it helps to focus main problematic area and the team find sources of waste. The next, the team define the main scope of the project

After the defined main scope of the project, some tools are used to capture the details of the project. For instance, in second and forth cases SIPOC was constituted by the team. In third case the team used the turtle diagram and flow chart. Another tool is process map, which are used in the reduced waste case.

After discussing and measuring current process with various ways which was depend on the issue of problem, fishbone diagram was created to define and group possible root causes. Also f(x) cascade method was used to define root causes at same cases.

When the team applied the fishbone diagram to first case, 21 causes were founded by the team. This number is too much for the analyze so that the team eliminated some causes with pareto charts, multi-vari charts, basic descriptive statistics and main effects plot. After this elimination, the main root causes, which were grouping with transfer functions and subgrouping methodologies, were determined. In second case, the team was used f(x) cascade and fishbone diagram to identify main root cause and they focused a specific machine which is needler. In third case, the team found several root causes and they created mind map with these causes. After analyze the mind map they reduced root causes to 4 main titles and determined the priority of the main root causes. In the last case which is the forth case , the pareto chart was used to eliminate root causes. Generally when the root causes are too many after the analyze fishbone diagram, the root causes are decreased and identify with several tools.

When the process variables are limited, the results are getting rapidly and the cost is not too high, design of experiments (DOE) is used to improve the process. For example, in this study DOE is used at manufacturing cases which are first and second cases. Main Root causes were eliminated with pareto chart and several tools in the reduce waste case and the variables are adapted to design of experiments. In second case, after the f(x) cascade analyzed the team decided to change the needler's settings and these settings are limited so that the team used DOE.

When the team decided to use DOE at the process, they used it until the result satisfied the team. For example, in first case the first DOE's results did not reach to target so the team changed the grouping method and after this the results reached to target values. In second case, the first DOE's results did not satisfied the team for th,s reason the team made an adjustment at the neeedler's setting and they got target results with new needler's settings.

In the other case, the characteristics of the cases are not applicable to DOE. Therefore the team made suggestion based on main root causes. In forth case the team was created action plan to improve process step by step. In third case, the team made suggestions based on priority and then these suggestions implement to the process respectively. End of the implementation, the results as compared to target values with several tools in third and forth cases.

At the end of all cases, when the team achieved to target values from the process, they made a training plan to all process participants. Besides that at the all cases the documentation has been made by the team. Thus, the improvement would be sustainable at the process and inspired to the future projects.

4.2.1. The Similarities of Applications

- The Six Sigma belt team was created in all cases. These is one of the key factors at the problem solving because the team members were selected based on their knowledge and areas of expertise. At the project every team member's responsibilities defined clearly. Each members who is participated was based on the requirements for an especial stage of the project, which contained define, measure, analyze, improve and control (DMAIC) methodology of the Six Sigma.

- Several tools, which shown in the table 4.12, are used in the all cases to identified project details and analyzed the collection data. These tools are used based on the project scope and data type.
- The problem was identifying clearly in the all cases. It’s the first step to solve the problem with right way.
- In the all cases, the all data is measurable and trackable at the current process and after the improvement.
- The Six Sigma was applied successfully and reached to target values in the all cases.
- In the all cases, the improvement has durability with training and documentation.

4.2.2. The Differences of Applications

- DOE was used to improvement the process in the manufacturing cases, which are first and seconnd cases. Besides that, in the other cases the team’s suggestion was used to improvement process.
- In first case the main goal is increased the productivity in the manufacturing process. However in second, third and forth cases the main goal is increased customer satisfaction.
- The research area might change in the all cases based on the source of main causes. For example, in first case the aim is reduced waste so that Six Sigma methodology is used to production process. On the other hand, in third case the aim is increased the customer satisfaction so that Six Sigma methodology is used to after sales process.
- Each case has different improvement level which is based on baseline values and target values.
- In some cases, the improvement level depends on suggestion. For example, in third case the second suggestion’s results satisfied to the team so that they did not apply the other suggestions. The team may apply the other suggestion in the future.

5. CONCLUSIONS

Six Sigma programs have been utilized as a structured methodology to improve organizational processes. With their focus on the viewpoint of customers, they systematically translate critical-to-quality characteristics into improvement projects. Successful implementation and growing organizational interest in Six Sigma method have been exploding in the last few years. The Six Sigma method is chosen a major driving force for improvement by the many organizations. The management involvement and organizational commitment, project management and control skills, cultural change, and continuous training are factors which determined the success of Six Sigma projects. When the organization understands the key features, obstacles, and shortcomings of Six Sigma, the organization takes a great opportunity to better implementation of Six Sigma projects.

When implementing Six Sigma, companies have the support of management, choose the correct projects which fit right to company strategies and customer expectations, found the right project team and move forward with the right tools and methods, it is certain they will get the expected benefits and solutions.

The companies which will put the customer satisfaction to their quality center will catch the change in global system and will be able to fulfill the requirements of heavy competition conditions. To implement Six Sigma philosophy to a company is not easy and is a long term job. Target should be implement Six Sigma philosophy sustainable and dominating the whole company. Effective Six Sigma principles and practices will succeed by refining the organizational culture continuously. Cultural changes require time and commitment before they are strongly implanted into the organization.

Six Sigma is likely to remain as one of the key initiatives to improve the management process than just being remembered as one of the fads. It wouldn’t be wrong to tell that Six Sigma will exist until it gains measurable financials to companies. And some of Six Sigma principles will show improvement over time, and some more new tools and techniques will be added.

5.1. Limitation of Six Sigma method

5.1.1. Limitation in Strategy

Hammer and Goding (2001) argued that Six Sigma has been the target of criticism and controversy in the quality community characterizing it as ‘Total Quality Management on

Steroid'. They said that the Six Sigma is just repackages traditional quality methods and principles so it is not new (Catherwood, 2002). Organizations need to understand that Six Sigma may not be at the first line to management strategy and it is not the answer to all problems of business. In order to ensure long-term Six Sigma method sustainability, strengths and weaknesses of the Six Sigma had need to analyze by the company and its tools, principles and concepts had used properly.

5.1.2. Limitation in Organizational Culture

At the manufacturing level, the organizations must add the quality concepts to process design rather than monitoring the quality (McCluskey, 2000). The change in the organization culture places quality into planning. The Six Sigma method helps the organizations to find addressing the issues and problems easily. When the organizations do not change all management plans or not understand all limits of Six Sigma projects, they are fail at the project. Senior management's strong commitment, support, and leadership are essential to dealing with any cultural issues or differences related to Six Sigma implementation. When the commitment and support do not exist for the Six Sigma projects, the organization might not implement Six Sigma.

5.1.3. Limitation in Training (Belt Program)

The one of the key factors is training in successful Six Sigma project implementation and it should be part of an integrated approach. The belt program should be applied to all levels of the company. This program should start from the top of the company. The belt program should reflect the organization's needs and requirements. Qualitative and quantitative measures and metrics, leadership, and project management practices and skills must be included to training program which is part of the development plan of producing different belt level experts. The latest trends, tools, and techniques of Six Sigma should be explained to attendees. When the black belt was selected from less-capable persons, the Six Sigma project met with challenges.

5.2. Future of Six Sigma

The organization should improve overall management performance not just counting defects and pinpointing. The innovative management techniques, which are Total Quality Management (Revere and Black, 2003), (Hammer and Goding, 2001), Human Resource Functions (Wyper and Harrison, 2000), Lean Production (Antony et al., 2003), ISO 9000

(Catherwood, 2002), ISO 9001 (Dalgleish, 2003), and the capability maturity model (Murugappan and Keeni, 2003), would be integrated to Six Sigma by researchers. With this action, Six Sigma may more attractive to different organizations and maximize the positive effect.

Leadership is one of a key success factor in implementing Six Sigma projects successfully. In the future, researchers might explain in details how and what leadership characteristics is needed for successful implementation of Six Sigma initiatives. Leadership contribution to Six Sigma has been discussed leading to the impact of leaders and leadership on Six Sigma critical success factors. Three hypotheses are proposed:

- Leader has a positive relationship with the successful implementation of Six Sigma.
- The successful implementation of Six Sigma has a positive relationship with leadership characteristics.
- The critical success factors of Six Sigma implementation are the role of leader and leadership.

The results from these studies will enable organizations to identify leaders and leadership variables that impact the successful deployment of Six Sigma.

REFERENCES

Abreu, P., Sousa, S. (2012). Using Six Sigma to Improve Complaints Handling. *Proceedings of the World Congress on Engineering* Vol III

Antony, J., Escamilia, J.L.,Caine, P (2003). Blending the Best of Lean Production and Six Sigma for Achieving and Maintaining Operational Excellence. *Manufacturing Engineer,*

Antony J. (2003). *Design of Experiments for Engineers and Managers Using Simple Graphical Tools*. Butterworth/Heinemann: Oxford.

Bakthavatchalam, S., Fallah, M. (2010). Delivering Record Products without Delays: A DMAIC Case Study

Banuelas R, Antony J. (2002). Critical success factors for the successful implementation of Six Sigma project in organisations. *The TQM Magazine*; 14:92–99.

Banuelas, R., Antony, J., & Brace, M. (2005). An application of Six Sigma to reduce waste. *Quality And Reliability Engineering International*, *21*, 553-570.

Barney, M., & McCarty, T. (2003). *The New Six Sigma –A Leader's Guide to Achieving Rapid Business Improvement and Sustainable Results*. Motorola University Prentice Hall USA.

Berryman M. (2002). DFSS and big payoffs. *Six Sigma Forum Magazine*; 2:23–28

Breyfogle, F. W. (1999). *Implementing Six Sigma: Smarter Solutions Using Statistical Methods.* John Wiley & Sons, Inc. New York.

Brue G, Launsbry R. (2003). *Design for Six Sigma*. McGraw-Hill: New York,.

Catherwood, P., (2002). What's different about Six Sigma. *Manufacturing Engineer* 81 (8), 186–189.

Chakraborty, A., Tan, K. (2012). Qualitative and quantitative analysis of Six Sigma in service organizations. In Aized, Tauseef (Ed.) *Total Quality Management and Six Sigma.* InTech, Croatia, pp. 247-286.

Dalgleish, S., (2003). My ideal quality system. *Quality* 42 (7)

Düğme, F.Z. (2008). "A Guide for Construction Companies to Apply Lean Six Sigma Methodology", Master Thesis, Middle East Technical University Master of Science in Civil Engineering Departmanet, Istanbul, Turkey.

Eckes G. (2001). *The Six Sigma Revolution*. Wiley: New York.

Eckvall D, Juran J. (1974). Manufacturing planning. *Quality Control Handbook*, Juran J, Gryna F, Bingham R (eds.). McGraw-Hill: New York.

Fornell, C., Mithas, S., Morgenson III, V.F., & Krishnan, M.S. (2006). Customer satisfaction and stock prices: high returns, low risk. *Journal of Marketing, 70*, 3-14

George, M. L. (2002). *Lean Six Sigma : Combining Six Sigma Quality with Lean Speed.* McGraw-Hill.

Gustafsson, A., Johnson, M.D., & Roos, I. (2005). Framework for comparing customer satisfaction across individuals and product categories. *Journal of Marketing, 69*, 210-218.

Hammer, M., Goding, J., (2001). Putting Six Sigma in prospective. *Quality* 40 (10), 58–62.

Han, C., & Lee, Y. (2002). Intelligent integrated plant operation system for Six Sigma. *Annual Reviews in Control, 26*, 27-43.

Harry M.(1994). *The Vision of Six Sigma*. Sigma Publishing Company: Phoenix, AZ.

Harry, M. (2000). *Six Sigma: the breakthrough management strategy revolutionizing the world's top corporations.* NY. Random House Publishers.

Harrold, D. (1999). Designing for Six Sigma capability. *Control Engineering*.

Hekmatpanah, M., Sadroddin, M., Shahbaz, S. (2008). Six Sigma Process and its Impact on the Organizational Productivity. *World Academy of Science, Engineering and Technology Vol:2*

Holtz, R., & Campbell, P., (2003). Six Sigma: Its implementation in Ford's facility management and maintenance functions. *Journal of Facilities Management, 2* (4), 320-329.

Jacobsen, J. (2011). Ford Team Project Builds Relationships, Improves Quality. *ASQ- Making the Case for Quality*

Johnson, A., Swisher, B. (2003). "How Six Sigma Improves R&D*", Research Technology Management*, 46, 12-15.

Keller, P. A. (2001). *Six Sigma Deployment – A Guide for Implementing Six Sigma in Your Organization* .QA Publishing.

Kiemele M, Schmidt S, Berdine R. (1997). *Basic Statistics: Tools for Continuous Improvement*. Air Academic Press: ColoradoSprings, CO.

Knowles, G., Johnson, M., & Warwood, S. (2004). Medicated sweet variability: a Six Sigma application at a UK food manufacturer. *The TQM Magazine, 16* (4), 284-292.

Kukreja, A., Ricks Jr, J.M., & Meyer, J.A. (2009). Using Six Sigma for performance improvement in business curriculum: a case study. *Performance Imprevement, 48* (2), 9-25.

Kumar, M., Antony, J., & Madu, C.N. (2006). Winning customer loyalty in an automotive company through Six Sigma: a case study. *Quality And Reliability Engineering International, 23*, 849-866.

Kumar, S., Wolfe, A. D., & Wolfe, K. A. (2008). Using Six Sigma DMAIC to improve credit initiation process in a financial services operation. *International Journal of Productivity and Performance Management, 57* (8), 659-676.

Kwak, Y.H., & Anbari, F.T. (2006). Benefits, obstacles, and future of Six Sigma approach. *Technovation, 26* (5-6), pp. 708-715.

Lin, C., Chen, F., Hung-da Wan, Kuriger, C., (2013). Continuous improvement of knowledge management systems using Six Sigma methodology. *Robotics and Computer-Integrated Manufacturing*, 29, 95-103

Linderman K., Schroeder R.G., Zaheer, S., Choo, A.S., 2003, "Six Sigma: a goal-theoretic perspective", Journal of Operations Management, 21, pp 193-203

Marx, M., (2010, November 20). Xerox lean Six Sigma. Retrieved from http://www.sixsigmacompanies.com/archive/xerox_lean_six_sigma.html

Mast, J., Lokkerbol, J. (2012).An analysis of the Six Sigma DMAIC method from the perspective of problem solving. *Int. J. Production Economics,* 139,604–614

McClusky, R., (2000). The Rise, fall, and revival of Six Sigma. *Measuring Business Excellence* 4 (2), 6–17.

Mijajlevski, A. (2013) The Six Sigma Dmaıc Methodology In Logıstıcs. *1st Logistics International Conference.*Belgrade, Serbia

Mital, A., Desai, A., Subramanian, A., Mita, A. (2008). Design Review: Designing to Ensure Quality. *Product Development: A Structured Approach to Design and Manufacture*, 71-90

Montgomery, D., Woodall, W. (2008). An Overview of Six Sigma *International Statistical Review,* 76, 3, 329–346

Murugappan, M., Keeni, G., (2003). Blending CMM and Six Sigma to meet business goals. *IEEE Software March.*

Nave D. (2002). How to compare Six Sigma, lean and the theory of constraints. *Quality Progress*; 35:3.

Pande, P., Neuman, R., Cavanagh, R. (2000). *The Six Sigma Way: How GE, Motorola, and Other Top Companies are Honing Their Performance* McGraw Hill USA.

Pandey, A. (2007). Strategically focused training in Six Sigma way: a case study. *Journal of European Industrial Training, 31* (2), 145-162.

Pfadt, A., & Wheeler, D. J. (1995). Using statistical process control to make databased clinical decisions. *Journal Of Applied Behavior* Analysis, 28, 349-370.

Process Quality Associates Inc, (2010, November 20). The evolution of Six Sigma. Retrieved form http://www.pqa.net/ProdServices/sixsigma/W06002009.html

Pyzdek, T. (1999). Six Sigma and beyond. Six Sigma is primarily a management program. *Quality Digest*, pp. 4-99.

Pyzdek T. (2001). *The Six Sigma Handbook*. McGraw-Hill: London.

Pyzdek, T. (2003). *The Six Sigma handbook: a complete guide for green belts, black belts, and managers at all levels.* McGraw Hill.

Rasis D, Gitlow H, Popovich E. (2002). Paper Organisers International: A fictitious Six Sigma green belt case study: I. *Quality Engineering* 15:127–145.

Revere, L., Black, K., (2003). Integrating Six Sigma with total quality management: a case example for measuring medication errors. *Journal of Healthcare Management* 48 (6), 377–391.

Schroeder, R., Linderman, K. (2008). Six Sigma: Definition and underlying theory. *Journal of Operations Management*, 26, 536–554

Sekhar, H., & Mahanti, R. (2006). Confluence of Six Sigma, simulation and environmental quality. *Management of Environmental Quality: An International Journal,* 17 (2), 170-183.

Shephered F. (1994).*Modern Coating Technology Systems*. Maclaren: Barnet, U.K.,

Xerox, (2010, December 10). Xerox Lean Six Sigma. Retrieved from http://www.xerox.com/downloads/usa/en/n/nr_XeroxLeanSixSigma_2004May.pdf