

**T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES**

**LEAN SIX SIGMA METHODOLOGY
AND AN APPLIED STUDY**

Canan YILDIRIM

**THESIS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL ENGINEERING**

**SUPERVISOR
Prof. Dr. S. Ümit OKTAY FIRAT**

İSTANBUL 2011

**T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES**

**LEAN SIX SIGMA METHODOLOGY
AND AN APPLIED STUDY**

**Canan YILDIRIM
(524408003)**

**THESIS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL ENGINEERING**

**SUPERVISOR
Prof. Dr. S. Ümit OKTAY FIRAT**

İSTANBUL 2011

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis supervisor, Prof. Dr. S. Ümit OKTAY FIRAT, for her guidance and supports during the preparation of this thesis. I would like to mention her invaluable experience and knowledge that helped me complete my study.

I would like to thank Gürsu Baskan for giving me an opportunity to work on a case study during my thesis.

I am also thankful to my family and my friends for their motivation and moral supports in successful completion of this thesis.

June, 2011

Canan YILDIRIM

CONTENTS

	PAGE
ACKNOWLEDGEMENTS.....	i
CONTENTS.....	ii
ÖZET.....	iv
ABSTRACT.....	v
LIST OF SEMBOLS.....	vi
LIST OF ABBREVIATION.....	vii
LIST OF FIGURES.....	viii
LIST OF TABLES.....	x
CHAPTER I: INTRODUCTION AND AIM.....	1
CHAPTER II: LEAN SIX SIGMA APPROACH.....	4
II.1 SIX SIGMA AND LEAN.....	4
II.1.1 Six Sigma Approach.....	4
II.1.2 Origin of Six Sigma.....	7
II.1.3 Origin of Lean.....	8
II.1.4 Lean Approach.....	11
II.2 LEAN SIX SIGMA METHODOLOGY.....	17
II.2.1 The Philosophy of Lean Six Sigma.....	17
II.2.2 The Essentials of Lean Six Sigma.....	18
II.2.3 The Four Keys of Lean Six Sigma.....	19
II.2.4 The Five Laws of Lean Six Sigma.....	27
II.2.5 Implementing Lean Six Sigma.....	28
II.2.5.1 DMADV and DMEDI.....	29
II.2.5.2 DMAIC.....	29
II.2.6 Using FMEA in Lean Six Sigma.....	43
II.2.6.1 Types of FMEA.....	43
II.2.6.2 Components of FMEA.....	44
II.2.6.3 Performing FMEA.....	45
II.2.7 How to Support Lean Six Sigma.....	48
II.2.8 Lean Six Sigma Approaches in the Literature.....	55

CHAPTER III:CASE STUDY IN AN ELECTRICAL COMPANY	61
III.1 COMPANY OVERVIEW	61
III.2 OBJECTIVES OF THE APPLIED STUDY	62
III.3 STEPS OF THE APPLIED STUDY	63
III.3.1 Define	64
III.3.2 Measure	69
III.3.3 Analyze	75
III.3.4 Improvement	79
III.3.5 Control	82
CHAPTER IV: RESULT AND DISCUSSION	84
CHAPTER V: CONCLUSION AND RECOMMENDATION	86
REFERENCES	88
RESUME	92

ÖZET

YALIN ALTI SİGMA METODOLOJİSİ VE BİR UYGULAMA ÇALIŞMASI

Global şirketler, dünyadaki yüksek rekabet nedeniyle, üretkenlik ve karlılıklarını artırmak için çok yönlü mücadele ile karşı karşıya gelmektedirler. Dünyada son dönemde görülen ekonomik durgunluk, şirketleri üretimde verimlilik ve süreç geliştirme konularına daha fazla odaklandırmıştır. Şirketlerin iş dünyasında kalıcı olabilmeleri için işletme maliyetlerini azaltırken, yenilik ya da ürün dizaynı yaparken ve kalite geliştirirken, israfı ve proseslerindeki sapmaları da azaltmaları gerekmektedir. Yalın Altı Sigma, düşük maliyet-yüksek karlılık, verimlilik, kalite ve rekabet gücü için çözüm sağlayan yeni bir üretim yaklaşımıdır. Yalın Altı Sigma; Yalın ve Altı Sigma yaklaşımlarındaki sapmayı azaltma ve hız özelliklerinin dengeli bir kombinasyonu ve birleşimi olarak işletme yönetiminin tüm optimizasyonunun başarılabilmesini sağlamaktadır.

Bu tez çalışmasının amacı, Yalın Altı Sigma Metodolojisi'nin literatür taraması ve tarihsel gelişimi hakkında bilgi vermek ve TÖAİK (Tanımla, Ölç, Analiz, İyileştir ve Kontrol) tekniğini bir elektrik firmasındaki bir ürünün teslimat süresi üzerinde uygulamasını yapmaktır. Teslimat sürecindeki hatalar; olasılıkları, şiddeti ve fark edilebilirliğine göre sınıflandırılmıştır ve hatalar üzerine daha sonra Hata Türleri ve Etkileri Analizi (HTEA) uygulanmıştır. Etkisi fazla olan hataların iyileştirilmesi için önlemler alınmıştır.

Haziran, 2011

Canan YILDIRIM

ABSTRACT

LEAN SIX SIGMA METHODOLOGY AND AN APPLIED STUDY

Global firms face multiple challenges of increasing productivity and profitability because of the highly competitive world. During the latest recessionary years around the world, organizations have focused all their efforts on gaining cost productivity and improving processes. They need to reduce waste and variation from their processes in order to remain in field while reducing costs from their operations, innovating or improving product design and quality. A new approach of production which provides a solution to the lower cost–higher profitability, the productivity, quality and competitiveness is Lean Six Sigma Methodology. Lean Six Sigma ensures an integrated and balanced combination of the speed and variation reduction power of both Lean and Six Sigma Approaches to achieve business management process full optimization.

The aim of this thesis is to give the literature review and historical evolution of Lean Six Sigma Methodology and apply DMAIC (Define, Measure, Analysis, Improvement, and Control) for decreasing the delivery time of a product in an electric company. Failure Mode and Effect Analysis (FMEA) is used for analysis of potential failure in the delivery process for classification by the severity, occurrence and detection. After the important failures are determined, the necessary improvements are taken.

June, 2011

Canan YILDIRIM

LIST OF SEMBOLS

ppm	: parts per million
C_p	: process capability
C_{pk}	: process capability index

LIST OF ABBREVIATIONS

LSS	: Lean Six Sigma
TPS	: Toyota Production System
TQM	: Total Quality Management
DMAIC	: Define, Measure, Analyze, Improve, and Control
DFSS	: Design for Six Sigma
DMEDI	: Define, Measure, Explore, Develop, Implement
DMADV	: Define, Measure, Analyze, Design, Verify
GE	: General Electric
WIP	: Work-in-process
DFLSS	: Design for Lean Six Sigma
SIPOC	: Suppliers, Input, Process, Output, Customers
CEO	: Chief Executive Officer
SE	: Sales Engineer
OPC	: Order Process Center
TCR	: Technico-Comm. Realisation
BEA	: Project Office
PL	: Planning
PR	: Production
CT	: Current Transformer
VT	: Voltage Transformer
CB	: Circuit Breaker
CTC	: Current Transducer
BOM	: Bill of Material
SOC	: Standards Oversight Council
RPN	: Risk Priority Number

LIST OF FIGURES

	PAGE
Figure II.1 : Concept of Variation and Sigma Level of a Proce	4
Figure II.2 : Two Processes with Identical Mean but Differing Variations	6
Figure II.3 : Commonly Used Six Sigma Techniques	7
Figure II.4 : The Improvement of Lean Six Sigma	10
Figure II.5 : Eight Types of Waste	12
Figure II.6 : Commonly Used Lean Techniques	15
Figure II.7 : The Keys to Lean Six Sigma	20
Figure II.8 : Variation in process outputs	22
Figure II.9 : Variation affects our ability to meet customer needs	23
Figure II.10 : DMEDI versus DMAIC	29
Figure II.11 : Sample Project Charter	30
Figure II.12 : SIPOC process diagram	32
Figure II.13 : Value Stream Map	33
Figure II.14 : Time Value Map	35
Figure II.15 : Pareto Chart and Time Series Plot	38
Figure II.16 : Example cause-and-effect diagram	38
Figure II.17 : Scatter Plot	38
Figure II.18 : PICK Chart	40
Figure II.19 : Control Chart	42
Figure II.20 : FMEA procedure	47
Figure II.21 : RACI chart used to define responsibilities	50
Figure II.22 : Organization of multiple Champions, Black Belts and Green Belts	52
Figure III.1 : The figures of SM6-36	62
Figure III.2 : The route of this study	64
Figure III.3 : Process Flow Chart for Delivery time	67
Figure III.4 : Pie chart of value & non-value added	71
Figure III.5 : Value & Non-value added for routes	71

Figure III.6	: Fishbone of long delivery time of SM6	73
Figure III.7	: Real and Target Value of the Main Process Steps	74
Figure III.8	: Pareto Chart of non-standard orders	75
Figure III.9	: Before and After Improvement of Control Chart of delivery time process	81
Figure III.10	: The histogram of delivery time before improvement	82
Figure III.11	: The histogram of delivery time after improvement	83

LIST OF TABLES

	Page
Table II.1 : Impact of Process Capability of One Sigma through Six Sigma for the Long Term When the Process Is Offset by 1.5 Sigma	5
Table II.2 : The Comparison of Traditional and Lean Six Sigma Methods	19
Table II.3 : Lean Six Sigma Toolset	42
Table II.4 : Non-linear scoring scale of the severity criteria	44
Table II.5 : Linear scoring scale of the probability of occurrence	44
Table II.6 : Linear scoring scale to the detectability criteria	45
Table II.7 : Example of FMEA form	48
Table II.8 : Literature studies according to sectors	60
Table III.1: SIPOC of the project	66
Table III.2: The percentage of routes	68
Table III.3: Value Added & Non value Added for Process	69
Table III.4: Value Added & Non value Added for Decision	70
Table III.5: Value Added & Non value Added for Terminator	70
Table III.6: Percentage of Value Added Steps for Routes	72
Table III.7: Descriptive statistics for main steps of process	72
Table III.8: FMEA Analysis of Non-Standard Orders	77

CHAPTER I:

INTRODUCTION AND AIM

Every corporation on our planet tries to figure out to outperform its rivals in two key business areas for managing its current business for maximizing profit and finding the future of its business for maximizing growth. The aim of the first task is to focus on activities and processes that enable flawless delivery of the promises to customers. The objective of the second task is to identify newer and better promises that will delight customers [1]. Global firms face several multiple challenges such as speed to market, top line growth, pricing, innovation, strategy execution, and productivity, profitability because of the highly competitive world [2]. During the latest recessionary years around the world, organizations have focused all their efforts on improving processes and gaining cost productivity [1].

A new approach of process improvement which provides a strong solution to the lower cost–higher profitability, the productivity, quality and competitiveness is Lean Six Sigma Methodology [3]. Lean Six Sigma (LSS) is the culmination of a variety of process improvement methods that combines lean manufacturing and Six Sigma from a global perspective that takes both suppliers and customers [4].

These methods began in the 1920s with the development of time, and the principles of statistical quality control. In the 1940s and 50s, Japanese firms had learned to apply statistical quality control in their manufacturing industries [3]. Ohno developed Toyota Production System (TPS), which provides many innovations including the concepts of waste reduction, quality, and continuous improvement [5]. During the 1990s Total Quality Management (TQM) was the dominant theoretical and empirical paradigm for quality management and included many of the elements advocated by leading quality thinkers such as Deming, Juran, and Crosby [6]. The Lean and TQM and the Six Sigma approaches are usually applied separately in firms, but recently there have been attempts to integrate them by firms called Lean Six Sigma [3].

Six Sigma approach was developed by Motorola Inc. in the mid-1980s to control variability in processes. The commonly accepted definition of a Six Sigma process is that produces 3.4 or fewer defects per million opportunities. Six Sigma is both a philosophy and a methodology that improves quality by analyzing data with statistics to find the root cause of quality problems and to implement controls. Statistically, Six Sigma refers to a process in which the range between the mean of a process quality measurement and the nearest specification limit is at least six times the standard deviation of the process [7].

The birth of “lean” was in Japan within Toyota in the 1940s: The Toyota Production System was based around the desire to produce in a continuous flow [5]. Lean Manufacturing or lean thinking is a method for reducing lead-time across the value chain, which improves cash flow, eliminates waste, reduces inventory and increases on-time delivery. Lean manufacturing is a business system for organizing and managing product development, operations, suppliers, and customer relations with higher quality and fewer defects - with less human effort, less space, less capital, and less time than the traditional system of mass production [3].

While Six Sigma is an approach to reduce operational variation and defects, lean thinking has ability of elimination of waste and reduction of cycle time. As an integrated strategy, Lean Six Sigma has now become a strong metaphor for a business excellence system that enables the breakthrough improvement in every part of the organization through process enablement, cost reduction, and increased profits. Lean Six Sigma is also a multifaceted business management system for achieving and sustaining innovation and revenue growth [1].

Literature review of Six Sigma, Lean and Lean Six Sigma was given comparatively and also the history of quality approaches were mentioned and the advantages and superiorities of using Lean Six Sigma Methodology in manufacturing field was also explained in the following chapters.

The objective of this study is to deal with Lean Six Sigma Methodology and to successfully implement the requirements of it in an organization using five step DMAIC (Define, Measure, Analyze, Improve, and Control) of Lean Six Sigma Methodology in electrical industry for the case of decreasing delivery time of a product. FMEA (Failure Mode and Effect Analysis) was applied to develop an improvement on the failure effects which affect to the delivery time mostly. After FMEA analysis, the actions taken were revealed to improvement for decreasing

delivery time of the product. As a result of the improvement, DMAIC cycle was evaluated in scope of the ability of the decreasing and reaching the target of delivery time. And according to the results of the application, the involved preventions and recommendations for decreasing defects and increasing speed and making lean was presented in this study if the level of Lean Six Sigma is lower than expected level.

CHAPTER II:

LEAN SIX SIGMA APPROACH

II.1 SIX SIGMA AND LEAN

In this chapter, six sigma and lean approaches are focused on, and historical evolutions of these approaches are brought out individually.

II.1.1 Six Sigma Approach

In the field of statistics, *sigma* (σ) represents the standard deviation (a measure of variation) of a population. However, this should not be confused with the notion of *sigma level* or *sigma score* of a process. Simplistically, the terms *six sigma process*, *sigma level*, or *sigma value* of a process refer to the idea that if six standard deviations between the mean of a process and the specification limit, virtually no items that exceed the specifications limits (see Figure II.1) [1].

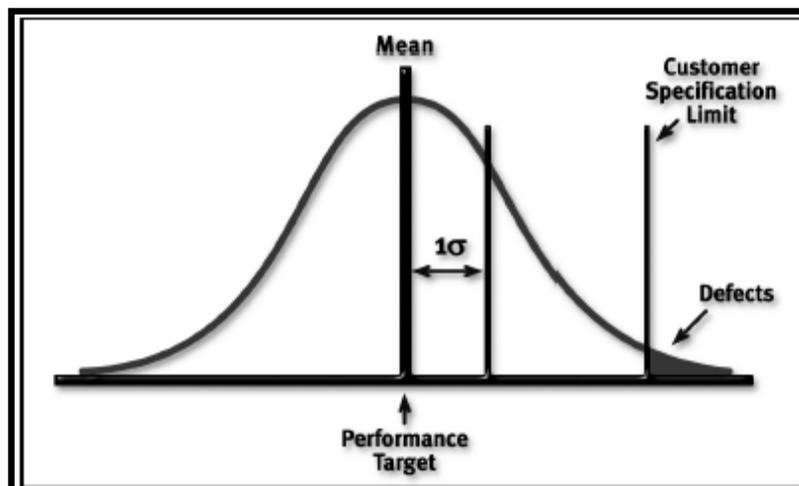


Figure II.1 Concept of Variation and Sigma Level of a Process [1]

As already noted, the commonly accepted definition of a Six Sigma process is one that produces 3.4 or fewer defects per million opportunities. Statistically, a normally distributed process will have 3.4 defects per million opportunities beyond 4.5 standard deviations above or below the mean. This would imply that 3.4 parts per

million defects correspond to 4.5 sigma and not 6.0 sigma. The 1.5 sigma that is added to 4.5 sigma refers to what is commonly known as *sigma shift*. It is based on the assumption that processes shift and drift over a long period of time. In the absence of specific data for a given process, we assume the shift to be approximately 1.5 sigma level. Therefore, a process capable of performing at 4.5 sigma level on the long term is assumed to be performing at 6 sigma level in the short term [1].

Table II.1: Impact of Process Capability of One Sigma through Six Sigma for the Long Term When the Process Is Offset by 1.5 Sigma [1]

Sigma capability	Defect free per million	Defects per million
0.0 Sigma	67,000	933,000
1.0 Sigma	310,000	690,000
1.5 Sigma	500,000	500,000
2.0 Sigma	691,700	308,300
2.5 Sigma	841,350	158,650
3.0 Sigma	933,193	66,807 (Traditional quality)
3.5 Sigma	977,300	22,700
4.0 Sigma	993,780	6,220
4.5 Sigma	998,650	1,350
5.0 Sigma	999,767	233
5.5 Sigma	999,968	32
6.0 Sigma	999,996.60	3.40

As sigma capability increases, the amount of defects decreases (see the Table II.1). Another important contribution of Six Sigma is reckoning the impact of variation in processes. Variation exists everywhere in nature; no two objects in nature are exactly identical. Therefore, it affects product performance, service quality, and process outputs leading to rework, scrap, and premium freight, all of which can cause customer dissatisfaction [1].

Variation causes uncertainty, risk, and potential defects. There are two types of variation; controlled and uncontrolled. Controlled variation, often referred to as common cause, is a stable or consistent pattern of variation over time (predictable). Uncontrolled variation, referred to as special cause, is a pattern that changes over time (unpredictable). To control and reduce variation, firstly understand, quantify, and interpret variation should be done in a data set. The mission of Six Sigma is to identify the areas of variation, isolate root causes, optimize processes and thereby

reduce or minimize the impact of variation in our products, processes, and services [1].

Let us demonstrate the impact of variation with the help of an example. Let us say there are two surgical operating rooms in a hospital performing identical functions. It has been decided to study the time it takes to prepare the rooms for surgical operations. Let us say that the average time to prepare the first room is 30 minutes, with high variations resulting in 50 percent of the time preparation procedures taking between 15 and 30 minutes and the other 50 percent preparations taking between 30 and 45 minutes. In the case of second room, average time to prepare is 30 minutes, with little variation resulting in rooms prepped in no more than 32 minutes (see Figure II.2) [1].

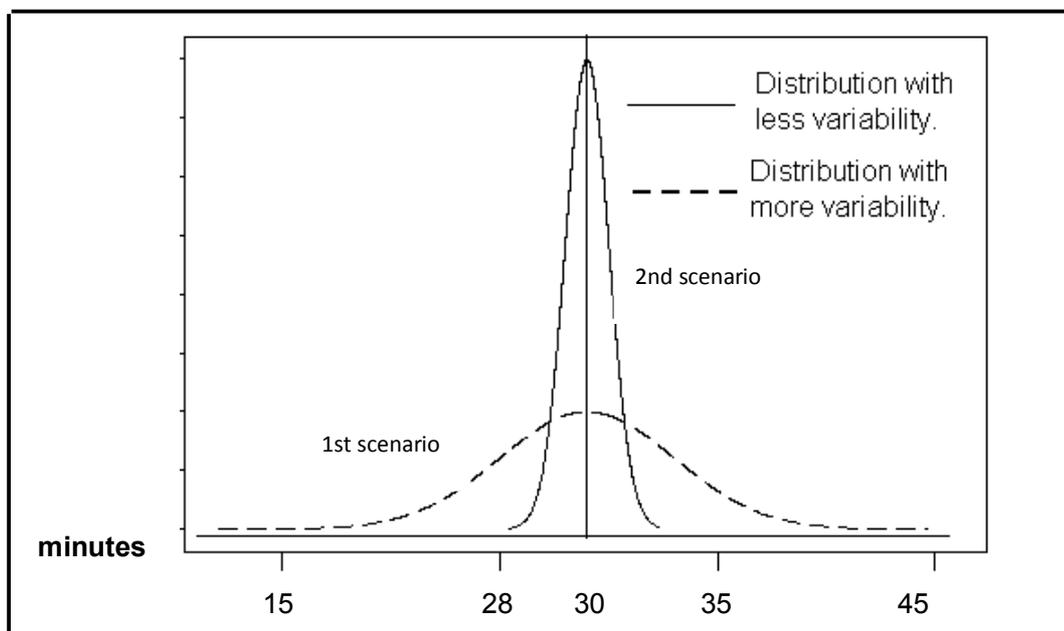


Figure II.2 Two Processes with Identical Mean but Different Variations [1]

Although the average time to prepare is identical, the second room provides consistently reliable support. Uncertainty caused by the first scenario can have a domino effect in downstream operations such as surgery. Customers feel the variation and always remember the extremes, not the average [1].

To drive dramatic improvements in performance, the variance in a process must first be minimized. The fundamental approach with Six Sigma is embodied in the equation $Y = f(x)$. Y represents the dependent or the output variable we are interested in for improvement. It can be a quality parameter such as reliability, yield,

or market share. The x variables are the independent or the input variables that affect the output variable Y . The objective is to characterize the relationship between Y and x . Six Sigma has a set of techniques that enable us to characterize and optimize the relationship between Y and x . Many of these techniques are shown in Figure II.3 [1].

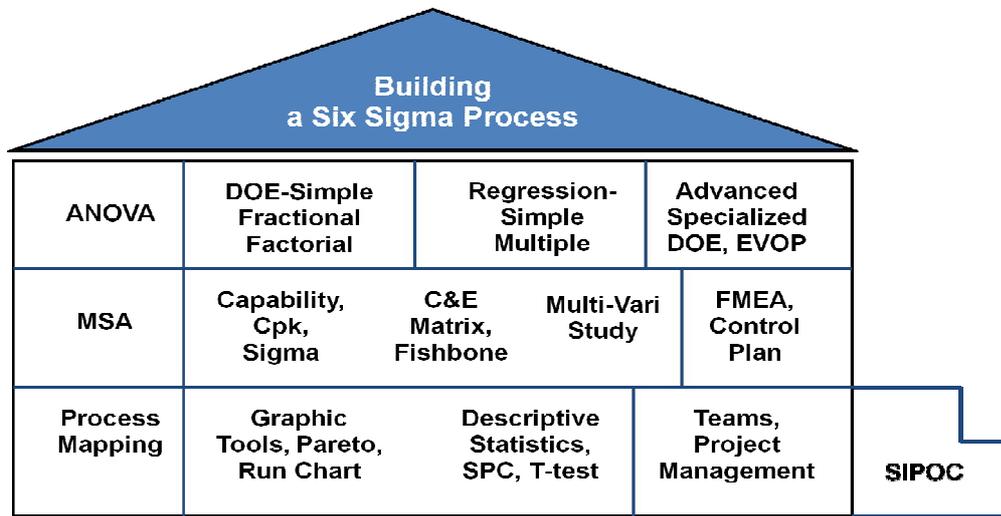


Figure II.3 Commonly Used Six Sigma Techniques [1]

II.1.2 Origin of Six Sigma

In the late 1700s, it was hard to find any textbooks on modern business management. However, *Miscellanea Analytica* (London: 1730) by the French mathematician Abraham De Moivre, the roots of a revolutionary management system based on the theory of probability can be found in it. Later Carl Frederick Gauss (1777–1855) added to De Moivre’s great contribution by developing the normal curve as a way to understand probability.

A couple of centuries later, other scientists and business leaders would build on De Moivre’s and Gauss’s work to find application in business management and hence reap breakthrough financial benefits. One such contribution came from Walter Shewhart, when he showed that three sigma distances from the mean is the point where processes require correction. Many process capability measurement standards such as Cp, Cpk, and ppm (parts per million) defects were later added. Although other noteworthy contributions came from Deming, Crosby, and Juran, credit for coining the term *Six Sigma* goes to a Motorola engineer named Bill Smith. Motorola first employed Six Sigma for quality improvement and to gain competitive advantage for its electronic products [1].

AlliedSignal then focused Six Sigma projects on cost reduction to realize over \$2 billion in savings in a four-year period. General Electric's spectacular success with Six Sigma in the 1990s convinced other organizations to embrace Six Sigma methodology. Multiple billions of dollars have been saved through the implementation of Six Sigma projects. Six Sigma was first developed as a statistically based technique to define, measure, analyze, improve, and control (DMAIC) manufacturing processes. To this end, its ultimate performance target is virtually defect-free processes and products (six sigma being the measure of 3.4 or fewer defects per million). Over a period of time, Six Sigma has evolved to become a vision, philosophy, goal, metric, improvement methodology, management system, and customer-centric strategy [1].

II.1.3 Origin of Lean

The roots of Lean can be traced back to the 1700s just like Six Sigma. It all started with Eli Whitney and his inventions of the cotton gin and interchangeable parts for gun. After graduating from Yale in 1792, Mr. Whitney was traveling west of Georgia when he noticed the difficulties growers had with cotton production. Growers had difficulty making money because removing seeds from the fibers required so much time and labor. By 1793, Whitney managed to invent a machine that mechanically separated seeds from fiber. This invention would eventually pave the way to the Industrial Revolution in English cloth manufacturing [1].

Later on, Whitney would turn his attention to the manufacture of guns. As the need for inexpensive but reliable firearms grew, he saw the potential for mass production using interchangeable parts. He demonstrated this concept in 1798 with the production of ten muskets, which culminated in an order from U.S. military for the manufacture of 10,000 muskets at a price of \$13.40 each. Although the production was late due to schedule overrun, he achieved success and sowed the seeds for the industrial revolution led by Henry Ford and others [1].

The next major round of contributions came from Frederick Taylor (1856 to 1915), Frank Gilbreth (1868 to 1924) and Lillian Gilbreth (1878 to 1972) in laying the foundations for industrial engineering. Taylor pioneered the idea behind time study and standardized work. He called it *scientific management* [1].

Frank implemented motion study and invented process charting, capturing value-added and nonvalue-added elements. Lillian Gilbreth studied psychology and

motivations of workers and investigated how attitudes affected the outcome of a process.

Henry Ford (1863 To 1947) is remembered for pioneering mass production, embracing the advances owing to Taylor and others. The hallmark of his contribution points to the River Rouge plant, where he installed a continuously moving assembly line for manufacturing the model T automobile. Ford is considered by many to be the first practitioner of just-in-time and Lean thinking [1].

After the war, Japanese industrialists studied many U.S. production methods, especially Henry Ford's mass-production system and quality improvement systems advanced by Shewhart, Deming, Juran, and others [6]. At Toyota Motor Company, Taiichi Ohno and Shigeo Shingo would implement many such approaches, including various elements of Ford's mass production system. During a trip to the United States, Ohno was inspired by the Indy 500 racing track, where race cars were getting refueled, tires changed, and serviced in the pit stop in an amazingly short time. Another observation he made was that in U.S. grocery stores, when the inventories were low on the shelf it triggered a replenishment signal to the suppliers. Therefore, material was replenished at the pull of the customers. The true spirit and practice of lean thinking is embodied in the inspirations from River Rouge plant, Indy 500, and U.S. super stores [1].

Taiichi Ohno is regarded as the founder of Toyota production system, the principles of which became later known as lean manufacturing [4]. James Womack and Daniel Jones (1991) coauthored a book called *The Machine that Changed the World* and coined the term *lean manufacturing*. This was followed up with another book, *Lean Thinking*, (2003). Womack and Jones provided a detailed and straightforward account of the Toyota production system and the associated Lean approach. [1].

The Lean Six Sigma historical evaluation can be summarized in Figure II.4.

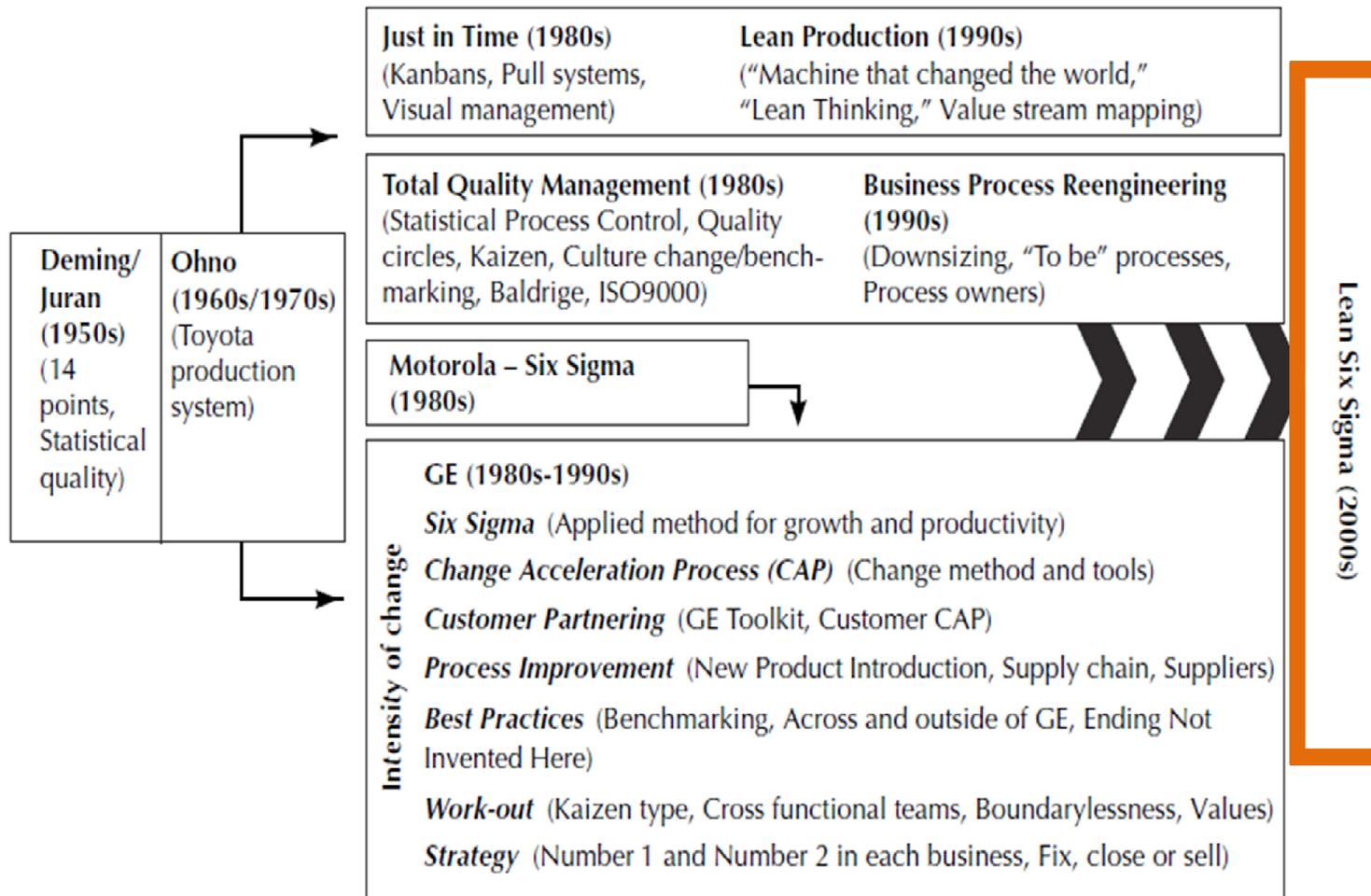


Figure II.4 The Improvement of Lean Six Sigma [1]

II.1.4 Lean Approach

The main theme behind Lean approach is to improve process speed and reduce cost by eliminating waste. Five basic principles of Lean, as explained by Womack and Jones are as follows [1]:

1. **Value** – Specify value in the eyes of the customer.
2. **Value stream** – Identify all the steps in the value stream and eliminate waste.
3. **Flow** – Allow the value to flow without interruptions.
4. **Pull** – Let the customer pull value from the process.
5. **Continuously improve** in pursuit of perfection.

Lean thinking has borrowed heavily from Little's law relating to lead time, work-in-process and average completion rate. It says that when the system is in a steady state;

$$\text{Lead time} = \text{Work-in-process units} / \text{Average completion rate}$$

Lead time is the amount of time accumulated between when work entered a process and work leaves the process. *Work-in-process* (or things-in-process) is the quantity of things currently inside the process. *Average completion rate* refers to the number of units processed per unit time. Therefore, the lead time for processing a claim may be calculated by dividing the number of claims-in-process inside the system with average number of claims processed in a given time. In product development, the work-in-process is the number of projects in process. In procurement, the work-in-process is the number of requisitions in process.

Lean approach has a set of well-defined tools that can identify opportunities for improving the average completion rate and reducing the work in process. Lean thinking uses a slightly different approach to problem solving than Six Sigma approach.

Progress is made through the execution of events called *Kaizen events*, wherein a small group of employees assemble together to improve certain aspect of the business through a series of quick, focused sessions. This approach reduces the long-cycle-time project mentality and creates a bias toward action. *Kaizen* is a Japanese word for incremental continuous improvement, with everyone working together.

The Kaizen approach for execution is as follows [1]:

1. Map out the current state and create a baseline.
2. Establish a vision for the future state.
3. Identify the gaps and establish opportunities for improvement.
4. Implement changes and remove waste from the system.
5. Evaluate results and institute continuous improvement.

The key thinking behind the Lean approach is to produce what is needed for the customer, when it is needed, with the minimum amount of resources such as materials, equipment, labor, and space.

The different types of wastes are classified as muda, muri, and mura that Japanese terms in Lean production. **Muri** is for overburden, unreasonableness or absurdity. **Mura** is for unevenness, inconsistency in physical matter or human spiritual condition. Waste reduction is an effective way to increase profitability. **Muda** is for an activity that is wasteful and doesn't add value or is unproductive. As shown in Figure II.5, Lean achieves this by attacking eight types of *muda* (Japanese word for “waste”) [1] (see the Figure II.5):

1. Waiting
2. Overproduction
3. Rework
4. Motion
5. Processing
6. Inventory
7. Intellect
8. Transportation

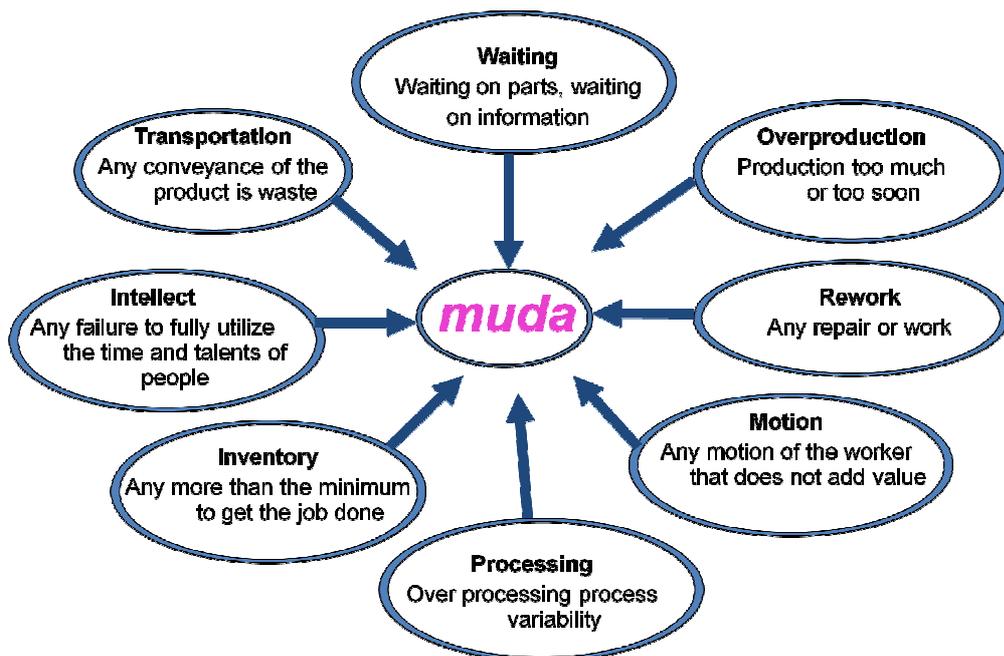


Figure II.5 Eight Types of Waste [1]

i) Waiting

In typical manufacturing processes, more than 90 percent of product's life is spent in waiting to be processed. Much of the time is spent waiting for the next operation. The waste of waiting applies to business processes as well. For example, documents waiting for processing and approval are a non-value-added activity and hence treated as waste.

ii) Overproduction

Producing more than what is necessary is the next type of waste. For example, imagine an automotive supplier produces certain transmission components according to a set schedule. In case of any excess of customer demand, it produces, and takes space, and all those products are tying up cash and holding it idle. In addition, they face the potential of getting damaged or obsolete. From a customer's perspective, the customer has to figure out and separate what is useful and what is unnecessary. From the provider's perspective, we have wasted resources and time to prepare and print unnecessary information.

iii) Rework

All the scrap and rework activities are obvious waste. This is straightforward and obvious in the context of manufacturing processes. For example, let us assume that our company manufactures hard disk drives for computers. During the manufacturing process, we may produce many components that might not be fit for assembly into the final product. Alternatively, we might have to rework these components to make them useful for final assembly. These are examples of waste. Rework activities are often called *hidden factory*. Rework is not as obvious in nonmanufacturing context. For example, often rework is built into transactional process in the name of *editing, approval, revision*, and others. Just like in manufacturing processes, our objective should be to get it done right the first time. A flawed strategy or decision can generate much rework for the company.

iv) Motion

Any movement in material that does not change form, function, or fit of the product is a waste from a Lean perspective. Any movement of people or machines that does not contribute to the added value of a product or a service is also a waste. For example, looking for parts, bending/reaching for materials, and searching for tools are examples of wasted motion in the context of manufacturing. Some motion

waste can be defined in the context of ergonomically inefficient motion. If an operation creates a repetitive stress injury, this is waste. In transactional processes, often documents are not placed in the most convenient manner or location for processing. This creates unnecessary motion that does not add any value.

v) *Processing*

When we process more than necessary, it is considered waste. Engineering change orders typically have many process steps that are not necessary from a customer value-added perspective. It is common for the change orders to go through multiple approvals and sign-offs that are not necessary. In manufacturing, we often perform a certain operation because it has always been done that way.

vi) *Inventory*

Producing and storing more products, material, parts, or information that is needed to fulfill current customer orders is a waste that falls in this category. In manufacturing context it includes raw materials, work-in-process, and finished goods. Inventory utilizes extra spaces and requires additional handling.

vii) *Intellect*

This refers to not taking advantage of the thinking power and knowledge base of human resources within the company. Failure to stimulate and capture ideas, not implementing employee suggestions, and poor communications are frequently cited example of waste in this category. Often due to administrative disconnectedness between employees, customer, and suppliers, many opportunities are missed. These, in turn, generate barriers to innovation, efficiency and unnecessary costs.

viii) *Transportation*

This refers to the unnecessary movement of parts, material or work-in-process from one operation to another. Transportation increases the overall time to process since no value-added activity is carried out during this time. Also, there is a time and resource cost associated with transportation. In addition, damages could occur during transportation. Poorly conceived layout of factory or facility is often the root cause behind this activity. We can eliminate this type of waste by improving the layout, process coordination, housekeeping, and optimization of operations. Lean approach is to first identify the product family, customer, and the value stream. By mapping out the value stream one can identify non-value-added activities that cause waste.

Lean has many techniques that allow us to map out and identify the value stream and the waste. These techniques are used to improve the value stream and

improve the process speed. Many of the commonly used techniques are shown in Figure II.6.

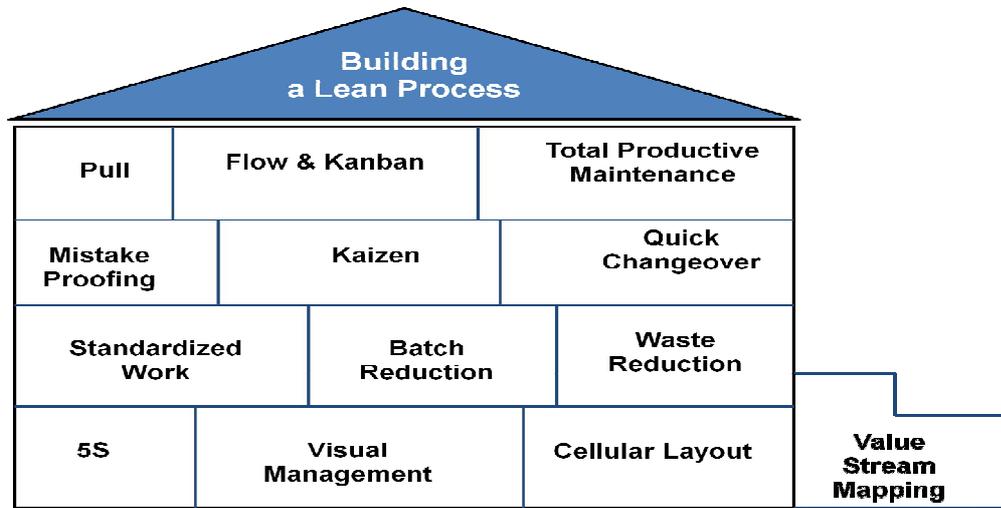


Figure II.6 Commonly Used Lean Techniques [1]

Lean Manufacturing is a term coined in the James P. Womack book, *The Machine That Changed the World*, based largely on his observations of the Toyota Production System. The focus at Toyota was **the absolute elimination of waste** that prevented the most optimum flow and assembly of material, from raw material to finished goods. A fundamental waste seen at Toyota and in every other manufacturing facility in the world was the overproduction of larger batches than what was needed by the next operation

A big part of lean manufacturing is the Kaizen and Kanban methods. But in a Toyota production system, these methods cannot exist alone without total facility analysis and the implementation of the lean process in general. The Kanban means one thing that is visible, in Japanese and according to the best lean manufacturing system every product should be made as one until it reaches the customer but this is not very efficient in production methods. Still there are ways of implementing the system of “one” within the lean manufacturing system.

Lean Enterprise: Lean technology has now evolved from the manufacturing floor to the whole enterprise. Lean follows the entire process from initial customer contact through ordering, fulfillment, billing and final payment. All of the various steps and sub-steps are tracked and scouted for waste. The result is an organization that is streamlined and efficient, eliminating waste and cost.

5S Workplace Organization: The 5S title is an acronym for the 5 Japanese words SEIRI (Sort), SEITON (Set in Order), SEISO (Shine), SEIKETSU (Standardize), and SHITSUKE (Sustain). A 5S programme is a process which when applied to a manufacturing, office or administration environment will result in moving from disorganization to organization. It is a process improvement tool with well defined outcomes resulting from implementing each of the 5 steps. The 5 steps or pillars are as follows:

- i. **Sort:** This is a process of removing all items from the work area that are not required. When this first pillar is well implemented, problems and annoyances in the workflow are reduced, communications are improved, product quality is increased and productivity is enhanced.
- ii. **Set in Order:** Items are arranged so that they are easy to find, use and put back to their predefined place. This helps to eliminate many types of waste in production and clerical activities.
- iii. **Shine:** One of the key purposes of shine is to keep all resources in top condition and ensure they are always available for use. When the third pillar is well implemented, improvements can be seen in reduction of safety hazards, improved morale, less equipment breakdowns, and a reduction in the number of defects.
- iv. **Standardize:** This pillar is the sustainment of the above 3 pillars, sort, set in order and shine. The basic purpose of standardize is to prevent setbacks occurring, to make them a daily habit, and to make sure they are maintained in their fully implemented state.
- v. **Sustain:** The fifth pillar involves make a habit of properly maintaining correct procedures over time. No matter how well implemented the first four pillars are, the 5s system will not work long term without a commitment to longer term sustainment.

Poka-Yoke: This is a mistake-proofing device or procedure to prevent or detect an error which adversely affects the product and results in the waste of correction. Its purpose is to provide some intervention device or procedure to eliminate the possibility of a mistake or at worst case to catch it before it is transitioned into the next level of product or consigned to nonconforming product.

Other than eliminating the opportunity for errors, mistake proofing is relatively inexpensive to install.

Kanban Pull: Kanban is Japanese word for “sign” It is a signal or communication system that is used as an integral part of Lean manufacturing so that customers can indicate when and in what quantities they require their materials to be replenished. Due to the critical timing and sequence of a kanban system, improvements are continually made. Typically immediate improvements to material availability and inventory reduction are noted on implementation of an effective Kanban system.

II.2 LEAN SIX SIGMA METHODOLOGY

Lean Six Sigma (LSS) is the culmination of a variety of process improvement methods that combines lean manufacturing and Six Sigma from a global perspective that takes both suppliers and customers [4]. In this section, Lean Six Sigma Methodology approach is explained with the historical background.

II.2.1 The Philosophy of Lean Six Sigma

Customer satisfaction also means profitability, is the number one priority in any organization. The success of any company depends on the ability to ensure the highest quality at the lowest cost. In the 1980s when most companies believed that producing quality products was too costly, Motorola believed the opposite: “the better, the cheaper”. It realized that by producing a higher-quality product, the cost of producing goes down. Motorola knew that greater customer satisfaction generates higher profitability [8].

Today the competitive market leaves no space for error. It is now necessary to implement the concepts of *Lean Six Sigma*. *Lean Six Sigma* is a business strategy in which the focus is to improve the bottom line and increase customer satisfaction [8].

Six Sigma philosophies are related to statistical process control, stochastic control (relating to probability), and engineering process control. In addition, it requires process and data analysis, optimization methods, lean manufacturing, and design of experiment, analysis of variance, statistical methods, mistake-proofing, on-time and or on-schedule shipping, waste reduction, and consistency assurance. It is a

process capability that continuously improves the quality of the product and maximizes productivity. In simpler terms, *Lean Six Sigma* is the following [8]:

- i) It is a data-driven approach and methodology to analyze the root causes of manufacturing and business problems/processes by eliminating defects (driving toward six standard deviations between the mean and the nearest specification limit), and dramatically improving the product.
- ii) It improves the employee's knowledge of business management to distinguish the business from the bottom line, customer satisfaction, and on-time delivery. Thus, *Six Sigma* is not just process-improvement techniques but a management strategy to manage the projects to financial goals.
- iii) It combines robust design engineering philosophy and techniques with low risks. It would be very difficult to achieve this goal without teamwork and proper training of the entire organization to a higher level of competency. During the 1980s *Six Sigma* grew into a distinct manufacturing discipline. It now encompasses a wide range of disciplines, including transportation, administration, manufacturing, medical, and a variety of other operating organizations and processes [8].

II.2.2 The Essentials of Lean Six Sigma

Corporations around the world attest to the benefits of implementing Lean Six Sigma strategy as demonstrated through its impact in financial savings and customer satisfaction. Lean and Six Sigma philosophy had separate origins. While Six Sigma was started as an approach to reduce operational variation and defects, lean thinking enabled elimination of waste and reduction of cycle time. Six Sigma and Lean are the twin forces that fuel any organization's drive for operational excellence. [1].

Typical Lean Six Sigma is aimed at reducing variation, defects, and waste, as well as improving process speed for existing processes and systems. These principles can be applied in a proactive manner to prevent defects and waste, while minimizing the impact of variation and enabling process speed. This is done in the context of designing and developing processes, products, and systems. Let's compare the traditional methods and Lean Six Sigma approach [1].

Table II.2: The Comparison of Traditional and Lean Six Sigma Methods [8]

Problem	Old methods	New methods
Design	Product performance	Product producibility
Analysis	Experience based	Data based
Issue	Fixing problems	Preventing problems
Manufacturing/ Molding	Trial & error process	Robust design process
Inventory level	High production quantity	Low production quantity as needed
People	Cost to company	Asset to company
Management	Cost & time	Quality & time
Employee goal	Company	Customer
Product engineering	Little input from customer	High input from customer
Quality focus	Product	Process
Dominant process factors—selection	Apply one factor at a time	Apply design of experiment
Process improvement	Robotic technique	Optimization technique
Proving	Experience based	Statistically based
Company outlook	Short-term plan	Long-term plan
Customer satisfaction	Production at statistical acceptance quality level	Fewer defects, when and what quantity customer wants
External relationship	Price relationship	Long-term relationship
Layout	Functional	Cell type
Production schedules	Forecast	Customer order
Manufacturing cost	Continuously rising	Stable and decreasing

In Table II.2, new methods mean lean six sigma, beside old methods mean six sigma, or only lean.

II.2.3 The Four Keys of Lean Six Sigma

All of the elements in the figures should be taken, working together, to create real solutions. You need to *combine* the creativity of people working on the process with data and with an understanding of customers and processes. Four keys of Lean Six Sigma are;

- Delight customers
- Improve the process
- Work Together for Maximum Gain
- Base Decisions on Data and Facts

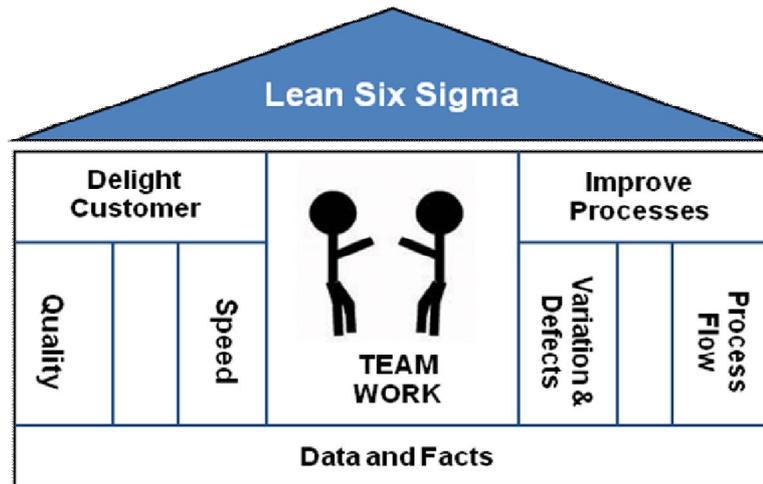


Figure II.7: The Keys to Lean Six Sigma [8]

Key 1: Delight customers

It used to be that a company would decide what features to include in its products or service based solely on what their engineers or marketing staff said they should be doing. Nowadays, those old-fashioned notions have been replaced by a new attitude that only customers can define quality. Customers are the people who will decide whether to spend their money on your company's services or products. They'll be comparing your offerings against everything else in the marketplace and determining which ones best fit their needs [9].

The goal: eliminate defects

Since Lean Six Sigma starts with customers, its goal is clear—to eliminate anything that doesn't meet their needs. In Lean Six Sigma terms, things that don't meet customer needs are called **defects**. One of the challenges you'll face as you begin to use Lean Six Sigma is defining and measuring defects [9].

The links between quality, speed, and low cost

When a product or service is ordered, we want it delivered as quickly as possible and on time (**speed**), with no errors (high **quality**), and at the lowest possible price (low **cost**). Lean Six Sigma cannot be studied when the goals are not achieved without doing speed, quality and low cost at the same time. Because;

1. A process that makes a lot of errors cannot keep up its speed. **So high quality makes it possible to attain fast speed.**
2. A process that works slowly is prone to errors (low quality). The key here is that we're looking at overall process speed, not how quickly an individual

person or machine works. **You have to do the things that create process speed (meaning “eliminate delays”) if you want to achieve the highest levels of quality.**

3. Low quality and slow speed are what make processes—and services and products—expensive. **So the only way to consistently offer the lowest price—and still make a profit—is to improve quality *and* speed [9].**

It’s because of these links that Lean Six Sigma offers advantages over other improvement methods. Traditionally, the methods called as “Six Sigma” focused more on quality than speed. The methods known as “Lean” are better at improving process flow and speed than on improving quality. Combining the two is what makes Lean Six Sigma such a powerful improvement tool [9].

Key 2: Improve the process

It is required that eliminate defects to do that and focus on how the work flowed through the process. Once you understand your customers, the next step is figuring out a way to get better at delivering what they want [9].

Dr. W. Edwards Deming, an American statistician who led the quality movement in Japan (and later in America), spent much of his time trying to convince people that most quality problems are “in the process, not the person.” He promoted his 85/15 rule, based on his experience that 85% of problems were *built into* the way work was done. Only 15% of the problems, he said, were really the fault of individual employees [9].

Most frontline employees had no trouble accepting Dr. Deming’s assertions. After all, they were the people who paid the price for a lack of training, poor equipment, little communication, and unrealistic goals. In short, they worked under conditions that *guaranteed* poor quality. It was often *managers* who resisted Dr. Deming, because they were trained to find “who to blame” when something went wrong [9].

In the last few years of his life, Dr. Deming admitted his 85/15 ratio was probably wrong. More than likely, he said, it’s 96% of problems that are built into the work *system*. Individual employees, he concluded, could only control perhaps 4%. That’s why Lean Six Sigma focuses on process improvement. In fact, the

purpose of most improvement efforts is to use data to find out what’s wrong in the system that allows the problems to happen in the first place [9].

There is a great deal of emphasis on for improving process: documenting how work gets done (the steps that comprise the process), examining the flow of work between people or workstations, giving people the knowledge and methods they need to constantly improve that work.

There are a lot of different process improvement methods, but almost all of them serve one of two purposes: to eliminate variation in quality and speed (a major source of defects) and to improve process flow and speed [9].

i) Eliminate variation

The Greek word “sigma” is used in statistics to stand for the amount of variation seen in a process, a set of data, or anything you can measure. To illustrate the concept, see two charts in Figure II.8. Each point represents a single measurement taken on a process. The top chart shows a process with a lot of variation or spread [9].

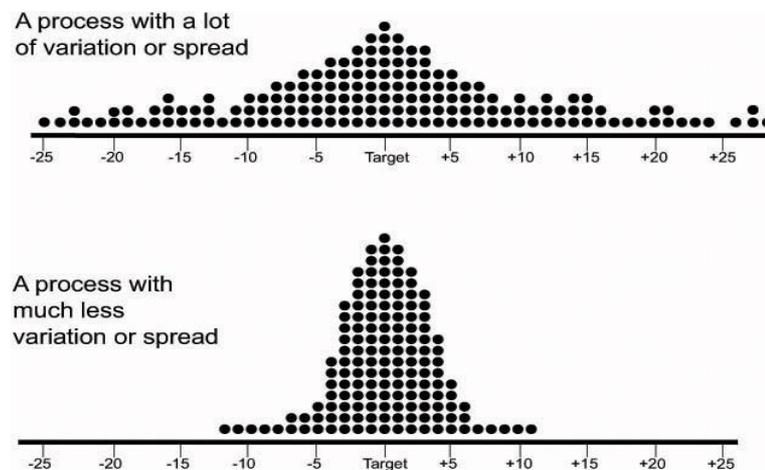


Figure II.8: Variation in process outputs [9]

ii) Variation defines the “sigma” level

We’ve taken the same charts and added lines to indicate what the customer *wants* (their ideal **target**), and what they will find acceptable. For example, a customer expecting delivery “by noon” (the target) might actually be happy if the package arrives anywhere from 11 a.m. to 1 p.m. A manufacturer that is purchasing 1000 gallons of paint (the target), might be satisfied if the delivery is 995 to 1005 gallons. In order to have an outcome with very little variation (see in Figure II.9),

everything leading up to that point has to work well. This explains why Lean Six Sigma focuses so much on process improvement. You need to make the work in your area more reliable, more predictable to reach high levels of quality which means eliminating variation [9].

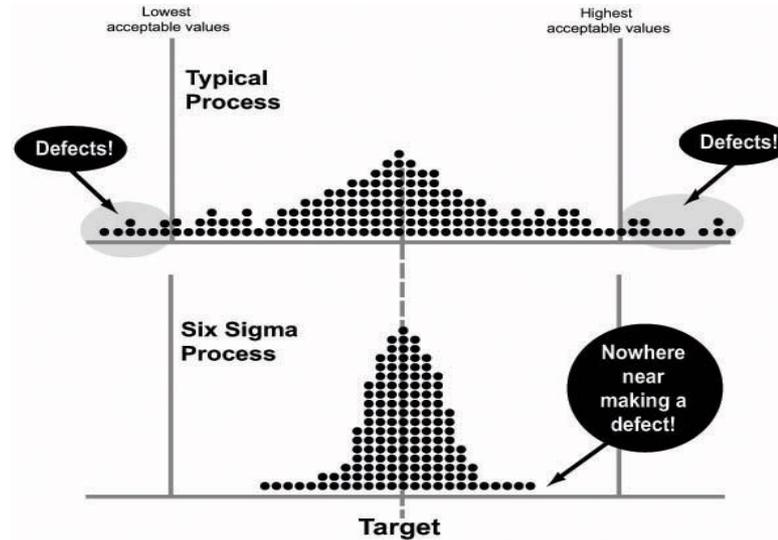


Figure II.9: Variation affects our ability to meet customer needs [9]

iii) Improve process flow and speed

Variation is one of the most common sources of problems in a process. But another source is how the work flows through the process. One of the best ways to speed up a process is to eliminate process steps that aren't really necessary meaning they don't meet a customer need. Another way is to redesign how work flows in the workspace [9].

Key 3: Work Together for Maximum Gain

In a Lean Six Sigma company, teamwork means feeling of “we’re all in this together.” is important for sharing and learning from each other. Another part is having an environment where people are encouraged to work together every day. [9]. Information is shared openly and freely, even “bad news” because it’s understood that hiding or distorting information won’t lead to real improvement.

i) Getting good at working together: the skills of collaboration

There are specific skills that all employees need to be trained in to have effective collaboration. They include [9]:

Listening skills: We listen to spouses, family, friends, coworkers, managers, store clerks everyone we deal with in the course of a day. Learning how to use listening to really understand what people are trying to say is a cornerstone of effective collaboration. Part of “listening” includes developing inquiry skills so you can draw information out of your teammates.

Brainstorming & discussion techniques: One of the reasons for having people work in groups is to tap into everyone’s ideas and knowledge. There are a lot of fun brainstorming techniques that get people to think creatively. And discussion techniques can help groups make sure that everyone gets a chance to be heard.

Organizing ideas: If you do a good job at listening, brainstorming, and discussion, many times you’ll end up with a long list of ideas. In most cases, it’s not practical or efficient to pursue each suggestion one-by-one. That’s why collaboration techniques include methods for sorting through, organizing, and prioritizing ideas.

Decision making: Teamwork comes with greater responsibility for everyone to actively participate in decision making. The skills and techniques you might find helpful include methods for determining how a decision should get made, which people or groups need to be included, what roles they should play, how to develop criteria for selection between options, and so on.

ii) Additional skills for effective teams

The collaboration skills discussed above are one aspect of getting people to work together as a team. Here are seven tips for avoiding those traps [9]:

1. **Set goals:** As a team, discuss the project goals. If everyone is not agree, resolve areas of disagreement or confusion.
2. **Assign accountability:** Whenever action is required, make sure that someone on the team is assigned the lead responsibility to see that it is done.
3. **Handle conflict:** The most effective teams reach a balance between openness and conflict. You want people to feel free to say what they think, because that’s the only way you can be sure you’re getting the best thinking from the team.
4. **Pay attention to how decisions are made:** Teams are brought together to make decisions about what needs to change in a process or product or service. So you will be judged largely on how effectively you reach good decisions.
5. **Make sure you have effective meetings:** There are a lot of specific meeting skills and techniques that can help your team have good meetings. Team

training courses usually cover topics like creating and using agendas, managing the meeting time.

6. **Foster continuous learning:** A goal of Lean Six Sigma teams is to constantly get better at improving their work, making decisions, holding good meetings. That's why they emphasize continuous learning, always going over what they've done, identifying what went well and what didn't, and finding ways to get better the next time around.
7. **Collaborate with other groups:** Lean Six Sigma teams are usually trying to improve procedures or a workplace where other people work. There are always people not on the team who have knowledge or skills the team could use. So learning how to work with other people and groups is another key to success. Your team will want to do things like talking to customers to see what they want from your product or service.

Key 4: Base Decisions on Data and Facts

Having data can make a huge difference in the decisions we make every day on the job, and is particularly important in improvement projects. Unfortunately, learning the data habit is harder than it has to be because of these reasons [9]:

1. **A lack of available data.** People working on early Lean Six Sigma projects are often starting from scratch when they begin to collect data. Do you know how much work you have in your process at this very moment? Do you know what your work group's error rate is on average? How many of your customers are happy with the product or service you provide? How many are unsatisfied?
2. **Little training in collecting or analyzing data.** If you've never had to collect data before, the number of decisions involved will probably surprise you. What data should you collect? How can you make sure it will answer the question your team is asking? How should you measure what it is you're trying to measure? How often should you take a measurement?
3. **A historical pattern of using data only to punish or reward individuals, not to make decisions about improvement.** For many years, a lot of organizations have used data for only one purpose: to punish or reward

people. What's very different in Lean Six Sigma organizations is that data is used for *learning* and for *monitoring process performance*. You will be collecting data to understand what's going on in the process, where problems are arising, and what solutions will really work.

The kinds of data

In general, it all falls into two categories: **result measures** and **process measures**; result measures reflect the *outcome* of a process or procedures—how the product or service turned out, process measures reflect what goes on to produce the result [9].

You need both results and process measures to be effective in Lean Six Sigma. You absolutely *have* to keep track of the final result. But the only way you can improve a result is to change the process, and you'll need process measures to tell you what has to change and how.

Here are four typical types of data that teams find useful [9]:

- a. **Customer satisfaction** (a result measure): Data gathered through surveys or interviews on what customers think about your product or service, and what it's like doing business with your group or organization.
- b. **Financial outcomes** (a result measure): What impact the quality and/or problems have on revenue, expenses, costs, etc.
- c. **Speed/lead time** (result or process measure): Data on how fast (or slow) your process is. "Lead time" is how long it takes for any individual work item to make it all the way from the beginning to the end of the process (when it is delivered to the customer). If measured at the end of the process, speed is a result measure. If measured on individual steps, it becomes a process measure.
- d. **Quality/defects** (result or process measure): How many errors are made, whether the product or service has flaws that affect the customer. Like speed, quality can be a result measure if the data are collected on the final product or service. But most teams also use it as a process measure, collecting data on what happens within the process.

II.2.4 The Five Laws of Lean Six Sigma

Law 1: The Law of the Market: Customer needs define quality and are the highest priority for improvement. You can't get sustained revenue growth without this.

Law 2: The Law of Flexibility: The speed of any process is proportional to its flexibility. If you want to be fast, you have to get rid of anything that causes a loss of productivity anytime people want to stop what they're doing and start on something new.

Law 3: The Law of Focus: Data shows that 20% of the activities in a process cause 80% of the problems and delay. So you'll make the most progress if you focus your efforts on those 20%.

Law 4: The Law of Velocity (Little's Law): The speed of any process is inversely related to the amount of WIP (work- or things-in-process). So as WIP goes up, speed goes down. As WIP goes down, a process speeds up.

$$\text{Lead Time} = \frac{\text{Amount of Work-In-Process}}{\text{Average Completion Rate}}$$

Lead time is how long it takes you to deliver your service or product once the order is triggered [9]:

To calculate the **process cycle efficiency**: the ratio of **value-add time** (work that *customers* would recognize as necessary to create products or services they are about to purchase) to **total lead time** (how long the process takes from start to end). Process cycle efficiency lets us gauge the potential for cost reduction.

$$\text{Process Cycle Efficiency} = \frac{\text{Value-add Time}}{\text{Total Lead Time}}$$

Let's look at one example. A supplier for major auto companies knew that there was less than 3 hours of value-add time in their process. However, the total lead time from release of raw material into the line to shipment was an average of 12 days. Based on having an 8-hour work day at the plant, the ratio of these two measures gives us process cycle efficiency:

Value Add Time = 3 Hours

Total Lead Time = 12 days * 8 hours/day = 96 Hours

Process Cycle Efficiency = 3 Hours/ 96 Hours = 3%

In other words, it was taking them 12 days to inject 3 hours of value into the product—the material is *waiting* for 11.6 days.

Law 5: The Law of Complexity and Cost: The complexity of the service or product offering generally adds more costs and WIP than either poor quality (low Sigma) or slow speed (un-Lean) process problems. So one of your early improvement targets may well be reducing the numbers or varieties of products and services your work group is involved in [9]. (This is a management decision that has to be based on good financial and market information.)

II.2.5 Implementing Lean Six Sigma

Every organization has problems that get “solved” over and over again, only to reappear. That’s why it uses a modern problem-solving method designed to avoid such problems. Lean Six Sigma projects follow three project methodologies inspired by Deming’s Plan-Do-Check-Act Cycle are;

DMAIC (Define-Measure-Analyze-Improve-Control)

DMADV (Define-Measure-Analyze-Design-Verify)

DMEDI (Define-Measure-Explore-Develop-Implement)

DMAIC is used for projects aimed at improving an existing business process. Beside, DMADV is used for projects aimed at creating new product or process designs. The preferred improvement model used for these situations goes by a number of names: some organizations call it DMEDI, some call it DMADV, and some just use the more general terms of Design for Six Sigma or Design for Lean Six Sigma (**DFLSS**). Though the labels differ, all are strategies for executing projects that require a significant amount of new design. DMEDI and DMAIC using can be seen in Figure II.

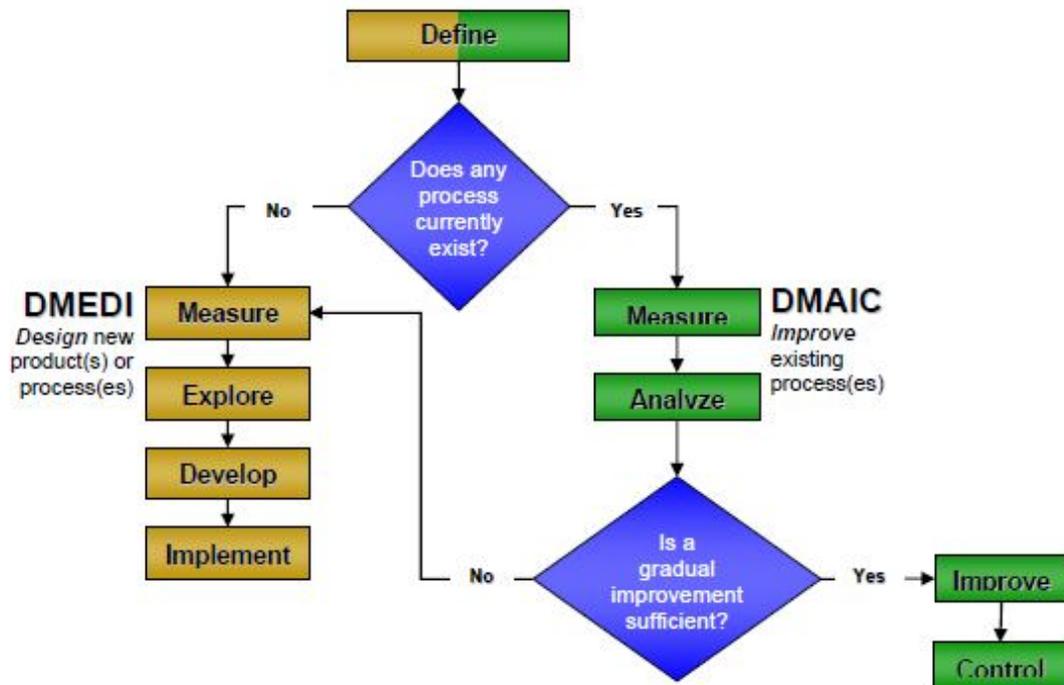


Figure II.10: DMEDI versus DMAIC [9]

II.2.5.1 DMADV and DMEDI

The DMADV project methodology, also known as DFSS, features five phases: Define design goals that are consistent with customer demands and the enterprise strategy. Measure and identify CTQs (characteristics that are Critical to Quality), product capabilities, create a high-level design and evaluate design capability to select the best design. Design details, optimize the design, plan for design verification. Verify the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

II.2.5.2 DMAIC (Define, Measure, Analyze, Improve, Control)

DMAIC has proven itself to be one of the most effective problem-solving methods ever used because it forces teams to use data to;

- Confirm the nature and extent of the problem
- Identify *true* causes of problems
- Find solutions that evidence shows are linked to the causes
- Establish procedures for maintaining the solutions even after the project is done

Before we get into the DMAIC process itself, you should be aware of what happens before a team gets started. Your management team will likely go through a project selection process to identify the projects they want to launch. The Champion (the corporate-level executive leading the Lean Six Sigma effort) will help your supervisor or manager draft a **project charter** to document what they want the team to accomplish [9]. Figure II.10 shows a project captures the essence of a project. It describes what the team should accomplish, who will work on the project (and in what roles), timelines, and other key information.

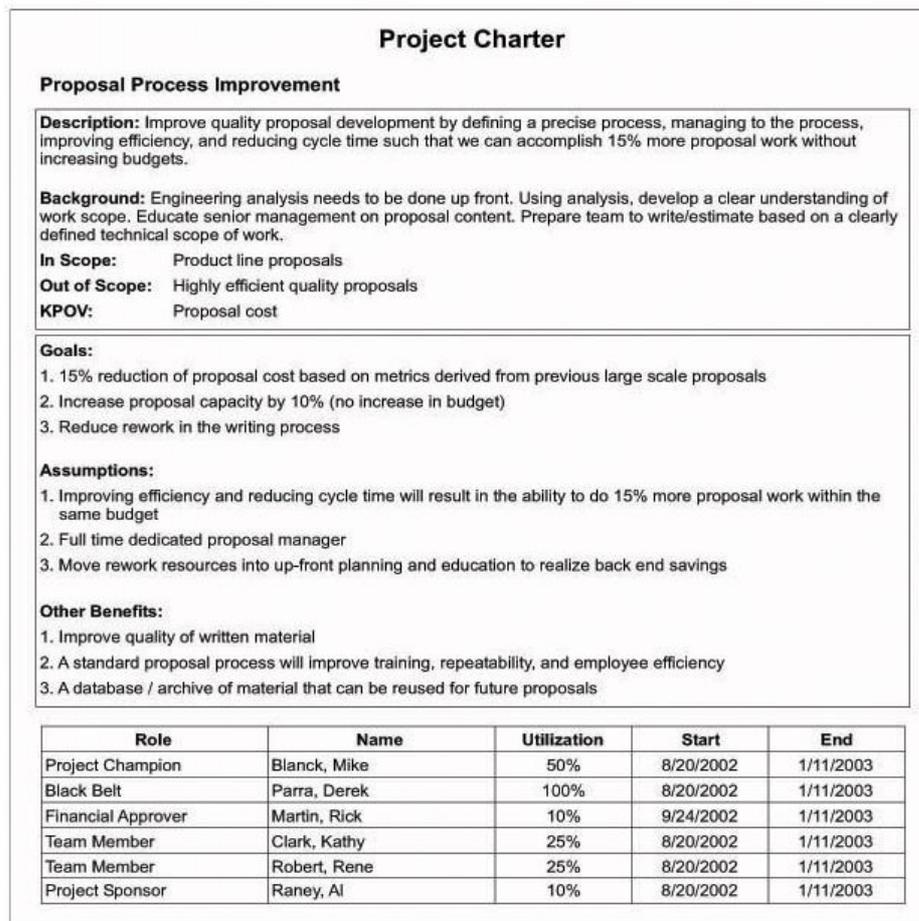


Figure II.11: Sample Project Charter [9]

Your team will be expected to fine-tune it once you begin studying the problem in detail. In some cases, you may discover information that will make management re-think the decision to work on the project in the first place or the problem may be much bigger than they thought, and there's no way the team can tackle it. For one thing, this helps remind team members about what they are supposed to do. It also gives them a chance to update the charter as they learn more information about the problem and its likely solutions [9].

DMAIC process is usually described as a “structured, data-based problem-solving process”. That means [9];

- i. Doing specific activities in a specific sequence
- ii. Gathering data in nearly every phase to help you make decisions
- iii. Making sure that the solutions your team decides to use really will eliminate the cause of the problem you’re trying to fix

i) DEFINE

The purpose of this first stage of the DMAIC process is for a team and its sponsors to agree on what the project is. The kinds of things you’ll do include [9];

- i. Discussing the project charter as a team.
- ii. Getting customer data.
- iii. Reviewing existing data about the process or problem.
- iv. Drafting a high-level map of the process.
- v. Setting up a plan and guidelines for your team.

Why should you do these things? They help [9];

- **Develop a *shared* understanding of the business priorities for your project.** (That word “shared” is key. Many teams get bogged down when people argue over what kind of data the team should collect or what solutions are best. That happens a lot when people don’t realize they have different ideas about what the team should be doing.)
- **Confirm the opportunity.** Talk to customers and look at any existing evidence to confirm that the problem that management wants you to solve is a real opportunity. This work will help you refine the project goals. In rare cases, a project may get canceled if the data does not support further work.
- **Reach agreement with management on a *realistic* scope for the project.** If your team thinks the project is too big (or too small), you need to negotiate with management to change the scope, add resources, and/or extend the deadline as appropriate.
- **Agree on how “success” will be measured.** A common mistake in the past was for teams and sponsors to NOT define up-front how they would know if the project is successful. A team would see the number of mistakes dropping,

Define Tool 2: Value Stream Map

SIPOC diagrams present a very simple view of a process, and are very useful for visually representing the basic elements of a process under study. But they don't really help a team understand what needs to be changed in a process. For that, you need more detailed process maps (also called "flowcharts") [9].

One type of process map used frequently in Lean Six Sigma projects is called a value stream map. These maps not only show the process flow, but also display actual process data. (See in Figure II.12). Because they include data, value stream maps can help teams pick out specific points in the process that have problems such as long wait times or lots of errors [9].

Value stream map in Figure II.12, based on an actual process, captures the main sequence of activities in the boxes across the top line. The triangles and other notations show wait times (delays) and rework loops (another form of waste). Notice that the order begins by waiting 125 minutes "in queue" at Bob's activity before he spends 8 minutes adding value. Then it waits 120 minutes at Judy's station before she adds 20 minutes of value, etc [9].

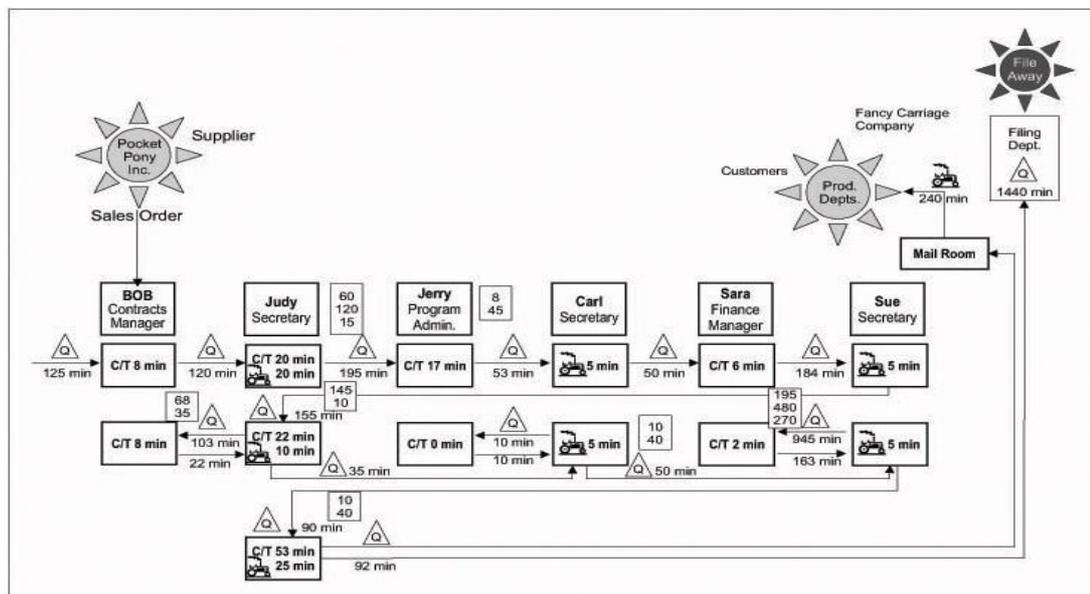


Figure II.13: Value Stream Map [9]

ii) MEASURE

Measure is the heart of what makes Lean Six Sigma work when other approaches haven't. If you don't gather data, you'll likely end up with a lot of quick-hit projects with short-lived or disappointing results. Combining data with

knowledge and experience is what separates true improvement from just tinkering with a process. In Measure you will [9];

- Evaluate the existing measurement system
 - Improving it if necessary
 - Developing a measurement system if you don't already have one
- Observe the process
- Gather data
- Map the process in more depth

Actions like these are necessary so you can [9];

- **TRUST your data.** You'd be surprised at how often a team spends a lot of time collecting data only to find out that their measurement system is unreliable.
- **Base decisions on facts and reality.** DMAIC is a data-based method. People's opinions still count, but everything must be checked against what the data is telling you.
- **Document what's really going on in the process.** It's just amazing how people who have worked on a process for a long, long time often don't realize everything that goes on. That's why a Lean Six Sigma team has to *document* what is really going on.
- **Understand what's important to improve.** Here's a tip that will make your task as a "process improver" much easier. *Of all the dozens or hundreds of actions you and your coworkers perform in your process, only a few of them make a real difference to your customer.*

Measure tool 1: process observation

We've already talked about the need to document or "map" a process. But before you even get to that point, what you need to do is simply go out and watch what's going on. There simply is no substitute for impartial observation as a way to confirm what really happens in a process and identify waste and inefficiencies that are built into how work is currently done [9].

Measure tool 2: time value map

A Time Value Map looks at how time is spent in a process. The chart consists of a timeline with bars broken out to highlight work that adds value in your customers' eyes and work that doesn't [9].

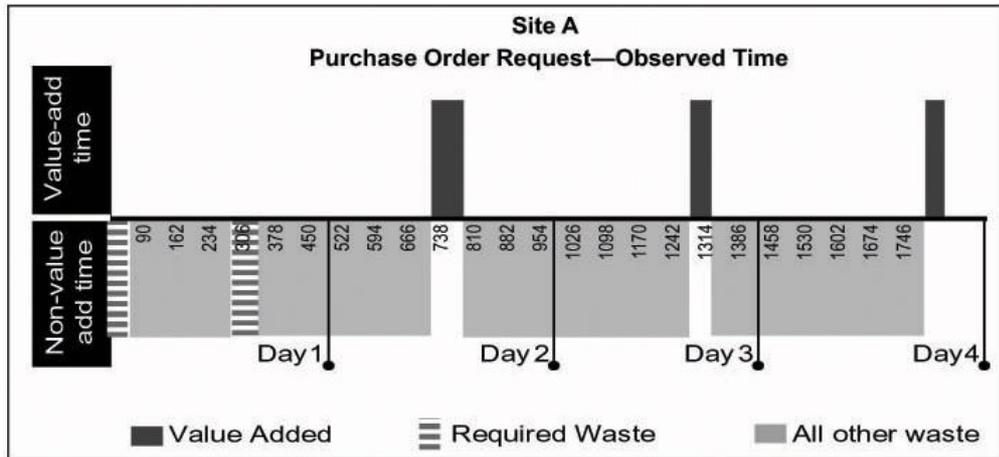


Figure II.14: Time Value Map [9]

Time Value Map in Figure II.13, the work that adds value is marked by a dark bar above the timeline. All the rest of the time is waste. In this case, there is some work that doesn't help customers (and, in that sense, is non-value-add) but that is required for accounting or tracking purposes. That's the "required waste" time shaded by stripes [9].

Measure tool 3: Pareto charts

One of the reasons why many improvement efforts have failed in the past is that people make *general* changes targeted at *general* problems. What's different in DMAIC is that you use data to pinpoint a *specific* cause of the problem. Then you develop solutions for that specific cause [9].

One of the most common tools used to help focus a team's efforts is a type of bar chart called a Pareto chart. In a Pareto chart, each bar represents a different element of a problem. The height of the bar shows how much of the problem is due to that cause, and the bars are arranged in descending order (as shown in Figure III.14). Almost always, the first few bars will be tall, and the rest will be *much* shorter. That means you can solve most of the problem if you take care of the issues represented by the tall bars—that is *focus* your efforts on the few biggest causes [9].

Pareto charts help focus a team on the biggest contributors to a problem. The chart in Figure II.14 shows how often different types of billing errors occurred. The team should focus its efforts on the first two types of errors, since solving those would reduce the number of defects by 80%.

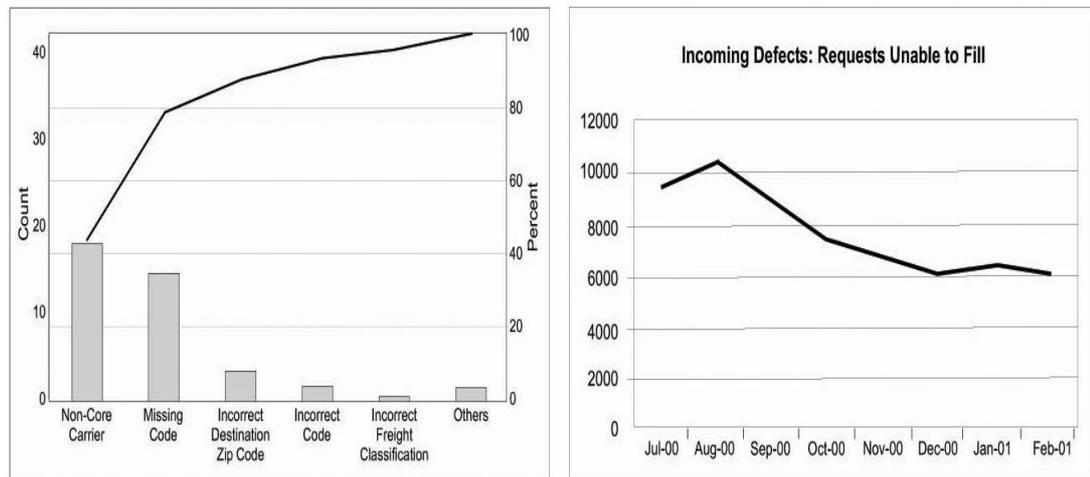


Figure II.15: Pareto Chart and Time Series Plot [9]

Measure tool 4: time series plots (also called “run charts”)

A time series plot is a chart where data points are plotted in sequence along a timeline (see in Figure II.14). Time plots are an important DMAIC tool for several reasons [9]:

- They are very easy to construct. Once you learn a few basics, you can create easily with entering the needed data into a software program.
- They are easy to interpret. There are just a handful of rules you can apply that will help you understand what you see on the chart.
- The interpretation rules expose patterns that help you pinpoint *when* and *where* problems occur. They also help you understand the *variation* in a process.

The challenges of data collection

If you’ve ever tried to gather data, you’ve probably encountered one or more of the following roadblocks [9]:

1. The data have never been collected before
2. The data have been collected, but for all practical purposes are unavailable
3. There is so much data that it’s difficult to figure out what has priority or what is most meaningful

4. The data does not really measure what you think it measures. If any of these conditions hold true for your team, expect to spend a lot of time deciding what data to collect and finding a way to collect it.

iii) ANALYZE

The purpose of the Analyze phase is to make sense of all the information and data collected in Measure, and to use that data to confirm the source of delays, waste, and poor quality. A challenge that all teams face in Analyze is *sticking to the data*, and not just using their own experience and opinions to reach conclusions about the root causes of problems. The things you'll do include [9];

- Looking for patterns in the data
- Targeting places where there's a lot of wasted time

These actions will allow [9];

- Find clues to the REAL causes
- Find ways to make the process faster without sacrificing quality
- Identify the most critical process factors to control

Analyze tool 1: cause-and-effect diagrams

A cause-and-effect diagram is a “thinking” tool that helps a team organize the ideas they have about potential causes of a problem. Organizing ideas this way serves two purposes [9]:

1. It helps a team make sure they haven't overlooked potential causes
2. It helps a team decide which causes to investigate further

A cause-and-effect diagram is sometimes called a **fishbone** (see in Figure II.16) because it resembles the skeleton of a fish. The team's problem statement is named in the “head” of the fish, with potential causes arranged in sets of “bones” linked to the head. The smallest bones are the most specific types of causes that contribute to the next larger level of bone. This team used a cause-and-effect diagram to make sure they had identified a wide range of reasons. The team then selected the ones they thought were most likely, and gathered data to see if their ideas were right [9].

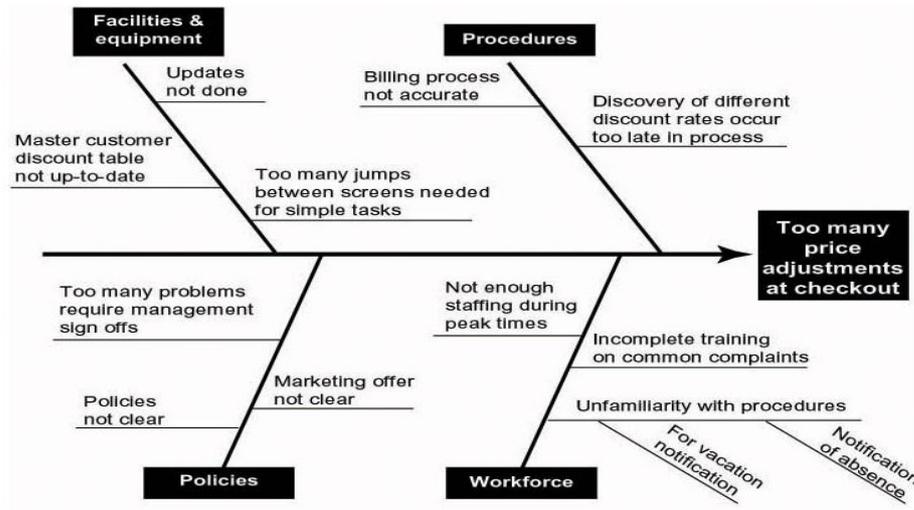


Figure II.16: Example cause-and-effect diagram [9]

Cause-and-effect diagrams do not tell you which of the potential causes is the culprit. They are just a good way for the team to document which theories it has considered, which have been targeted for further investigation, and, ultimately, which have been verified.

Analyze tool 2: scatter plots

The scatter plot is a simple tool that can help determine if a relationship exists between two measures or indicators. The example shown in Figure III.17 was created to explore whether broker experience affected how long it took to complete client calls. The downward slope of the line shows that more- experienced brokers are able to complete calls more quickly [9].

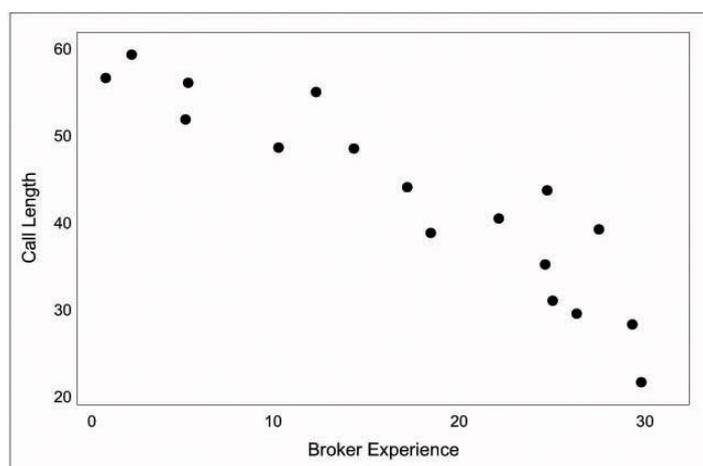


Figure II.17: Scatter Plot [9]

If customer satisfaction was high with the shorter calls, the team would then have to see what the experienced brokers knew that let them get done faster, and transfer that knowledge to less-experienced brokers [9].

Scatter plots provide a powerful visual image of how potential process factors are related to a key outcome. Often, the visual impression is enough to confirm a specific course of action. If necessary, more advanced statistical tools can be used to quantify the degree of relationship between the two factors [9].

iv) IMPROVE

The sole purpose of Improve is to make changes in a process that will eliminate the defects, waste, costs, etc., that are linked to the customer need identified in the Define stage. The team must make sure that the causes they're looking at in Improve affect the problem or need defined in its charter. The changes they make must affect the causes they confirmed in Analyze. The things include [9];

- Using creativity exercises to identify a range of possible solutions (rather than rely on things that are tried-and-true)
- Reviewing existing Best Practices (documented procedures known to produce good results) to see if any can be adapted to your situation
- Developing criteria for selecting solutions
- Piloting the chosen solution
- Planning for full-scale implementation

What does this get you? It will help your team [9];

- *Not* get stuck with the same old solutions that don't work
- Develop new solutions that you **KNOW** are linked to the **REAL** causes
- Justify/explain why one solution was chosen over another
- Learn about what will and won't work in reality

Improve tool 1: PICK chart (evaluating solution alternatives)

One of the simplest ways to compare alternative solutions is using the **PICK chart** (Figure II.18). On this type of chart, your team just needs to identify how much effort it will take to implement your solution ideas, and what kind of payoff you expect. Performing this analysis helps you decide which ideas you should

implement for sure, which may need more work, and which ones you should just abandon.

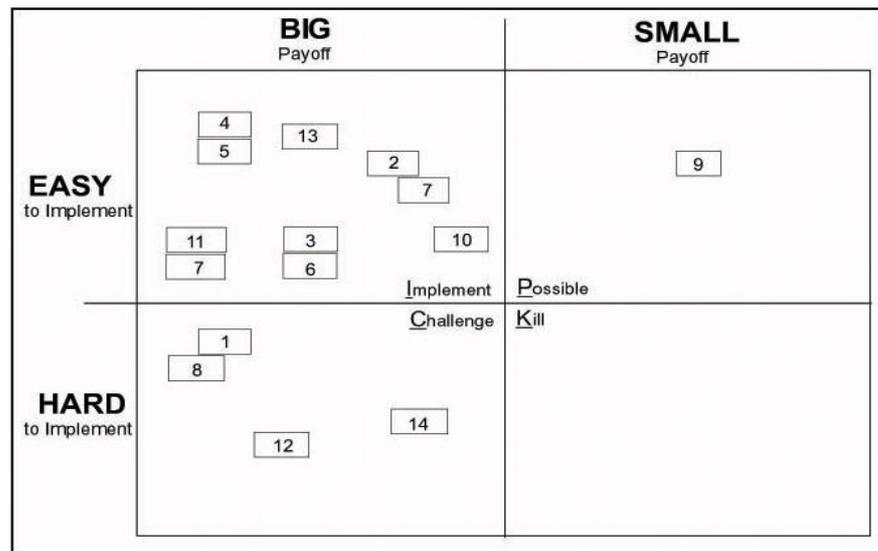


Figure II.18: PICK Chart [9]

A PICK chart helps a team organize and prioritize its solution ideas by separating them into four categories: Possible, Implement, Challenge, or Kill. Here, most of the solution ideas were easy to implement and would have a big payoff—they fell into the implement quadrant. Four ideas would have a big payoff but were harder to implement, so the team needed to Challenge these ideas. Only one idea had a small payoff, and therefore was considered. Possible; no ideas fell into the automatic Kill category [9].

v) **CONTROL**

The purpose of Control is to make sure that any gains your team makes will last. That means creating procedures and work aids that will help people do their jobs differently from now on. The team must transfer what they learned to the process owner and ensure that everyone working on the process is trained in using the new, documented procedures. In Control you will [9];

- Document the new, improved procedures
- Train everyone
- Set up procedures for tracking key “vital signs”
- Hand-off ongoing management to the process owner
- Complete the project documentation

The actions will help [9];

- **Prevent backsliding.** Changing habits is a lot harder than changing the switches on a machine. The actions listed above will make it easier for people to use the new procedures and NOT slip back into the old way of doing things.
- **React quickly to future problems.** Tracking the vital signs for your process will help you respond quickly when and if new problems appear. The sooner you react, the more likely you are to be able to find the cause and put a new solution in place.
- **Share the learning with others in your organization.** Chances are there are other people in your organization doing the same kind of work that you do, or at least something very similar. Having your team's work documented in a simple way will help other people share the learning and insights from your team.

Control tool 1: control charts

Probably the most common tool in Control is a control chart, which you can think of as a super-charged time series plot. Like a time plot, the data points are plotted in time order. But control charts have additional lines on them (**control limits**) that are used for interpreting patterns in the data. (See in Figure II.19) Basically, if any points go outside the control limits, that's a signal of unusual variation. Someone should investigate what's going on in the process right away [9]. Like a time series plot, a control chart starts by charting the data in the order in which they are collected. The points hover around a center line, drawn at the mean (average). The two outer lines- one above and one below the mean-are called "control limits". The distance between the control limits indicates how much variation can be expected in the process. Points that go outside the limits are signals that something odd or unusual is happening that the team needs to investigate. (There are several signals seen on the chart).

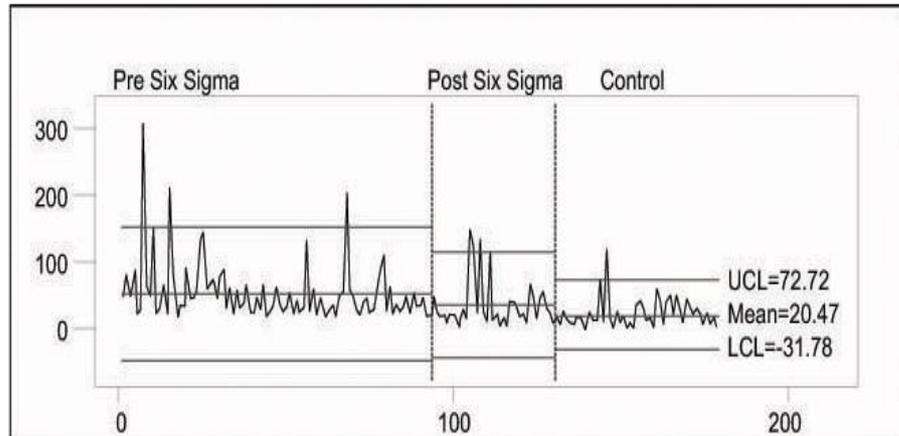


Figure II.19: Control Chart [9].

In conclusion, commonly used toolset in Lean Six Sigma is given according to five phases in Table II.3;

Table II.3: Lean Six Sigma Toolset [10]

Define	<ol style="list-style-type: none"> 1. Establish Team Charter 2. Identify Sponsor and Team Resources 3. Administer Pre-Work 	<ul style="list-style-type: none"> • Project ID Tools • Project Definition Form • NPV/IRR/DCF Analysis 	<ul style="list-style-type: none"> • PIP Management Process • SSPI Toolkit
Measure	<ol style="list-style-type: none"> 4. Confirm Team 5. Define Current State 6. Collect and Display Data 	<ul style="list-style-type: none"> • SSPI Toolkit • Process Mapping • Value Analysis • Brainstorming • Voting Techniques • Pareto Charts 	<ul style="list-style-type: none"> • Affinity/ID • C&E/Fishbones • FMEA • Check Sheets • Run Charts • Control Charts • Gage R&R
Analyze	<ol style="list-style-type: none"> 7. Determine Process Capability and Speed 8. Determine Sources of Variation and Time Bottlenecks 	<ul style="list-style-type: none"> • C_p & C_{pk} • Supply Chain Accelerator • Time Trap Analysis • Multi-Vari • Box Plots • Marginal Plots 	<ul style="list-style-type: none"> • Interaction Plots • Regression • ANOVA • C&E Matrices • FMEA • Problem Definition Forms • Opportunity Maps
Improve	<ol style="list-style-type: none"> 9. Generate Ideas 10. Conduct Experiments 11. Straw Models 12. Conduct B's and C's 13. Action Plans 14. Implement 	<ul style="list-style-type: none"> • Brainstorming • Pull Systems • Setup Reduction • TPM • Process Flow • Benchmarking • Affinity/ID • DOE 	<ul style="list-style-type: none"> • Hypothesis Testing • Process Mapping • B's and C's/Force Field • Tree Diagrams • Pert/CPM • PDPC/FMEA • Gantt Charts
Control	<ol style="list-style-type: none"> 15. Develop Control Plan 16. Monitor Performance 17. Mistake-Proof Process 	<ul style="list-style-type: none"> • Check Sheets • Run Charts • Histograms • Scatter Diagrams 	<ul style="list-style-type: none"> • Control Charts • Pareto Charts • Interactive Reviews • Poka-Yoke

II.2.6 Using FMEA in Lean Six Sigma

FMEA was applied first time at USA army named as “Procedures for Performing a Failure Mode, Effects and Criticality (FMECA)”, with MIL-P-1629 code, as a reliability evaluation technique to determine the effects of system and equipment failures. FMEA may be applied to either processes or products, therefore making it applicable to both lean Six Sigma for service and lean manufacturing Six Sigma efforts. Today FMEA harmonizes to FMECA because of including this criticality analysis. FMEA was used by NASA from 1965 to 1969 for Apollo project which lands on moon with men [11].

Common uses for Failure Mode and Effects Analysis in either environment include [12]:

- i. The design of new processes
- ii. Rework of existing processes for better performance
- iii. New applications or environments for existing processes
- iv. As a proactive follow-up to a problem-solving study
- v. Upon determination of a preliminary process understanding
- vi. Upon definition of system functions are defined, prior to selection of hardware
- vii. Upon definition of product functions, prior to design approval and release.

II.2.6.1 Types of FMEA

The FMEA is not a new tool. The aerospace industry used the FMEA during the Apollo missions in the 1960s. Later in 1974 the US Navy developed MIL-STD-1629 which discussed the proper use of the tool. And around this time the automotive folks latched onto the tool and never let go. Today, the FMEA is universally used by many different industries. Failure analysis is widely applicable to a number of industries and areas within a single organization. While applications may vary, the basic principle of forecasting potential failures and creating proactive responses is a cornerstone of quality lean Six Sigma implementation [14].

- Process FMEA: Used to analyze manufacturing and/or assembly process.
- System FMEA: Used to analyze complete systems and/or sub-systems during the concept of design stage.

- Design FMEA: Used to analyze a product design before it is released to manufacturing.

II.2.6.2 Components of the FMEA

i) **Severity:** In general, severity assesses how serious the effects would be should the potential risk occur. In the example of a manufacturing process for a drug substance, the severity score is rated against the impact of the effect caused by the failure mode on the batch quality [15]. A non-linear scoring scale can be applied to augment the effect of the severity criteria as shown in the table below.

Table II.4: Non-linear scoring scale of the severity criteria [14]

Severity		
Value	Description	Criteria
1	Irrelevant	No impact to product quality and process robustness
4	Slight	No impact to product quality
9	Important	Noticeable impact to product quality, but can be recovered by reprocessing
16	Critical	Definite impact to product quality that may require rework
25	Disastrous	Batch failure, not recoverable by rework

ii) **Probability of occurrence:** In general, the probability of occurrence evaluates the frequency that potential risk(s) will occur for a given system or situation. The probability score is rated against the probability that the effect occurs as a result of a failure mode. The example below applies a linear scoring scale to the probability of occurrence of failure modes associated with the manufacturing process of a drug substance [14].

Table II.5: Linear scoring scale of the probability of occurrence [14]

Probability		
Value	Description	Criteria
1	An unlikely probability of occurrence	Failure has never been seen in any relevant lab experiments, or scale-up batches yet but it is theoretically possible.
3	A remote probability of occurrence	Failure only seen once or twice in relevant lab experiments, never in scale-up batches.
5	An occasional probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up. If procedures are followed the failure potential is minimal.
7	A moderate probability of occurrence	Failure potential has been noted in several relevant lab experiments, or at scale-up, in-process control maybe required to avoid failure.
9	A high probability of occurrence	Failure potential has been noted in several relevant lab experiment, or at scale-up, an active non-standard feed back control loop may be required.

iii) Detectability: In general, detectability is the probability of the failure being detected before the impact of the failure to the system or process being evaluated is detected. The detectability score is rated against the ability to detect the effect of the failure mode or the ability to detect the failure mode itself. The example below applies a linear scoring scale to the detectability criteria in an FMEA for a drug substance manufacturing process [14].

Table II.6: Linear scoring scale to the detectability criteria [14]

Detection		
Value	Description	Criteria
1	High degree of detectability	A: Validated automatic detection system that is a direct measure of failure. B: Two or more manual operated validated detection systems, direct or indirect. (e.g. Control range and IPC)
3	Good detectability	A: Single manually operated validated detection system that is a direct measure of failure. (e.g. IPC of failure, validated PAT)
5	Likely to detect	A: Single manually operated validated detection system that is not a direct measure of failure. (e.g. PAT measurements or IPC's not directly linked to failure)
7	Fair detectability	A: Non validated (manual or automated) detection. (e.g. visual level check, visual inspection of vessels).
9	Low or no detectability	No ability to detect the failure

II.2.6.3 Performing FMEA

This analysis is a rather straightforward process. All probable failure modes should be identified first. This could be the manner in which a product fails during use or a process fails to meet customer requirements, such as excessive delays in order processing. Past experience, performance review and brainstorming sessions are all reliable sources of this information. New processes or products lacking a history of data can be examined using proxy data from similar processes or products. Each possible failure mode is then assigned a value between one and ten in terms of severity, occurrence probability and detection probability. These three values are then multiplied to yield a Risk Priority Number (RPN). Priorities are determined upon the value of each failure's RPN; the greater the value, the more severe the issue. To safeguard against failure, lean Six Sigma efforts should include the assignment of a target RPN value [13].

Steps of performing FMEA [13] (See the Figure II.20);

1. Describe the product or process.
2. Review a block diagram of the product or flow chart of the process.
3. Complete the headers of FMEA table as customized for the specific need.
4. Break down the product or process into its components or steps and list each step or component under the column with the header of “Parts/Components” in the FMEA Table.
5. Identify all potential failure modes associated the product component or process step.
6. List all potential failure modes for each item (product component or process step under the “Failure Mode” column in the FMEA Table.
7. Describe the effects of each of the listed failure modes and assess the severity of each of these effects on the product or process. Assign a severity rating to each effect on the FMEA Table.
8. Identify the possible cause(s) of each failure mode.
9. Quantify the probability of occurrence of each of the causes of a failure mode.
10. Identify all existing controls (Current Controls) that contribute to the prevention of the occurrence of each of the causes of a failure mode.
11. Determine the ability of each of the listed controls in preventing or detecting the failure mode or its cause. Assign a ranking score to indicate the detection effectiveness of each control.
12. Calculate the Risk Priority Number (RPN) = (SEV x OCC x DET).
13. Identify actions to address potential failure modes that have a high RPN
14. Assign an individual responsible for implementation of the defined action(s) and a target date for completion.
15. After the defined actions have been implemented the overall effect on the failure mode that the actions were supposed to address must be re-assessed and a new RPN calculated.
16. The new RPN will help to determine if further action needs to be taken.
17. Update the FMEA Table every time there is a significant change in the product design or process.

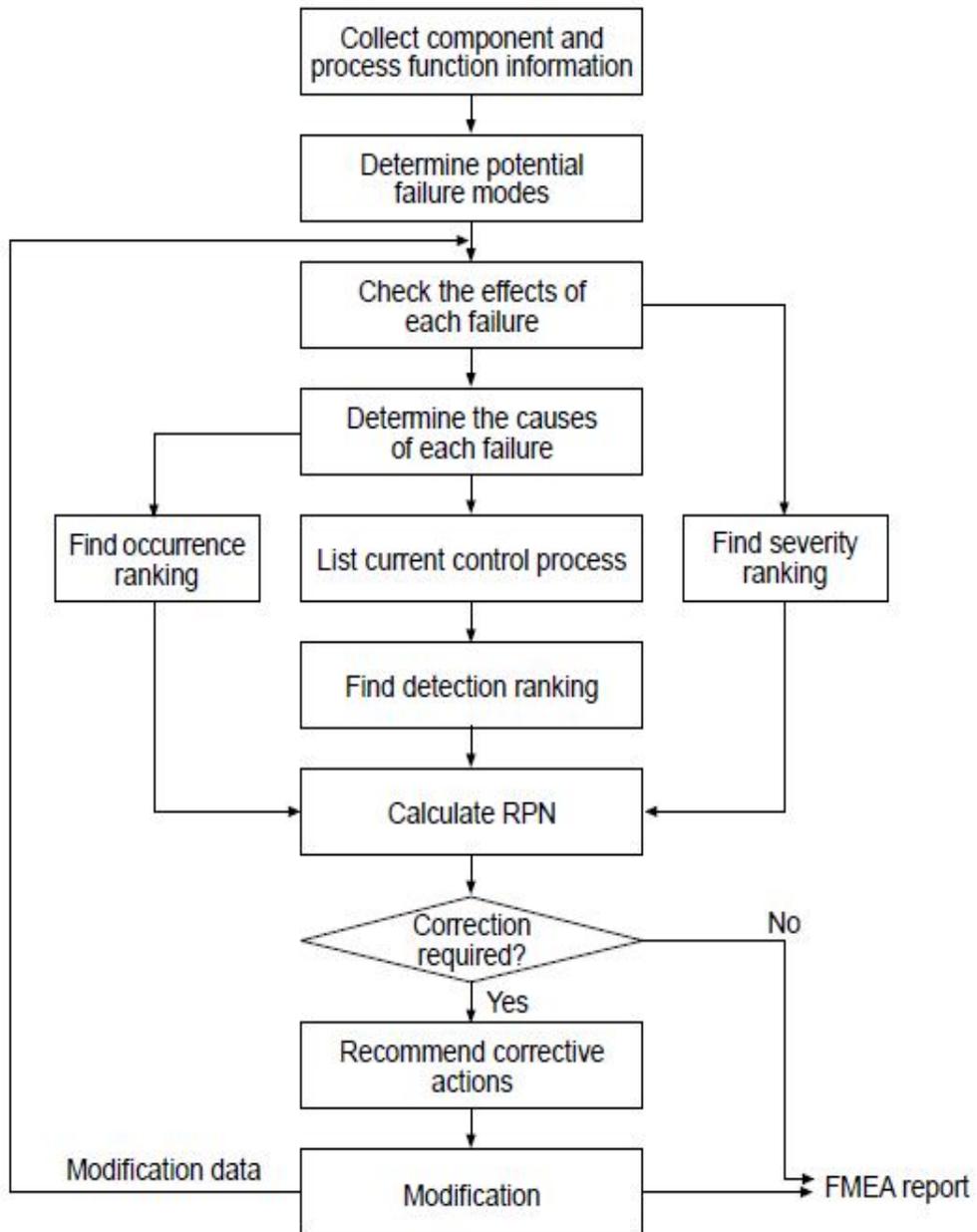


Figure II.20: FMEA procedure [13]

Table II.7: Example of FMEA form [14]

Lean Six Sigma process more than pays for its costs during the first year of implementation.

2. Pick the right people

Going into details is beyond the scope of this subject, but be aware that a lot of people have spent a lot of time developing methods that can help you identify the individuals or groups (and the combination of skills, abilities, personalities) to fill the new positions [10].

3. Follow the method

The vast majority of methods and techniques associated with Lean Six Sigma have evolved over the past few decades (or longer). They are based on a lot of experience with what does and doesn't work in practice. You can be a more effective manager if you adopt Lean Six Sigma practices such as [10];

- i. Always asking to see the data when employees present you with a suggestion or idea.
- ii. Working with a Black Belt to develop ways to “make waste visible” in your work area. Simple data charts and flow charts, maintained by you or your employees, can keep people focused on improvement goals.
- iii. Fully participating in the DMAIC reviews for teams working on issues that affect your work area.

4. Clearly define roles and responsibilities

In setting up a Lean Six Sigma infrastructure, you also set up potential conflicts in authority and responsibility. Being clear about the responsibilities of both the management and Lean Six Sigma roles will help you avoid innumerable conflicts. A **RACI** format that helps people sort out and clarify responsibilities is a useful tool for this situation. The letters stand for different levels of expectation [10]:

- i. **Responsibility**, for people who are expected to actively participate in the activity and contribute to the best of their abilities
- ii. **Accountability**, denoting the person ultimately held responsible for the results
- iii. **Consultation**, for the people/groups who either have a particular expertise they can contribute to specific decisions (i.e., their advice will be sought) or

who must be consulted with for some other reason *before* a final decision is made (e.g., finance is often in a consultation role to projects)

- iv. **Inform**, for the people/groups who are affected by the project but who do not participate in the effort (they are usually notified of the outcome after the final decisions are made)

Figure II.21 shows an example of how you can document the way you would like roles and responsibilities to work, but the specifics will vary for your organization.

Activity=> Task	Own the LSS Deployment	Identify Projects	Select Projects	Project Results	Project Execution	Team Support	Sustain Changes
Exec Team	A	R	A				
Champion	R	A	R			R	
P&L Management		I		A		R	R
Process Owner		C		R	R	R	A
Black Belt		C		R	R	A	
Tm Leader/Green Belt				R	R		
ETC							

Figure II.21: RACI chart used to define responsibilities [10]

RACI chart provides to determine the balance of power between Black Belts and teams. Black Belts are put in a delicate situation: On the one hand, they have a lot of knowledge that teams and line management can use to make the project a success. On the other hand, if they *impose* their knowledge on those they are helping, they're sending the message that Lean Six Sigma means "do it my way." As a rule, Black Belts should be positioned in the role of *support staff*, not decision-makers, because they are not "experts" in nor do they have any ongoing responsibility for the work [10].

5. Communicate

The managers and others leading a Lean Six Sigma effort face a lot of competing pressures. They have to select and launch projects, make sure training is set up and delivered, provide support to people working on projects, and on and on.

They need to put time into creating a web of communication with all parts of the organization [10]:

1. **With bosses**, to make sure everyone understands corporate priorities. Communication with corporate leaders can also be vital in helping to overcome roadblocks or resolve conflicts that may arise between departments.
2. **With project team members**, to make sure they are clear on the purpose, goals, boundaries, and expectations for their project. The manager should also invite communication *from* the team, so they will feel comfortable asking questions, pushing for clarity, and so on.
3. **To and from staff** (and the rest of the organization). In general, the more that employees at all levels are aware of what's going on and why, the more likely they will be to support Lean Six Sigma efforts either directly or indirectly.

6. Support education and training

Lean Six Sigma isn't yet a course in most universities or colleges, let alone high schools. So most people in the workforce—including managers like you—will need to be trained and educated. Managers' responsibilities are to [10];

- **Educate themselves:** If you want to have role models, try watching what CEOs like Lou Giuliano of ITT Industries and Vance Coffman of Lockheed Martin are doing. Both have participated in their organizations' executive-level training in Lean Six Sigma.
- **Support the education of their staff:** The combination of these specialized "Belt" positions, as they are called, plus other staff involved in Lean Six Sigma is often called the Lean Six Sigma "infrastructure." Here again, each organization will have its own infrastructure, but let's look at seven typical roles and how they relate to Lean Six Sigma:

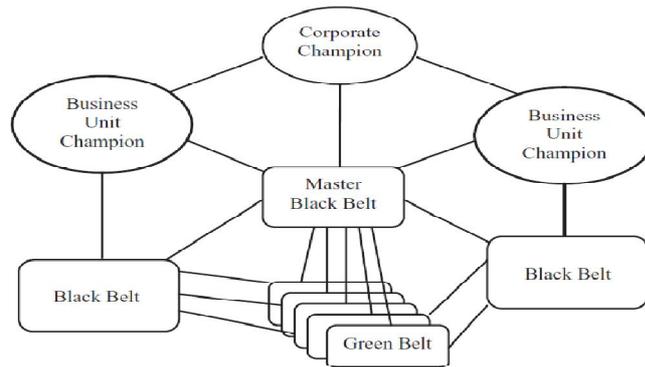


Figure II.22 Organization of multiple Champions, Black Belts and Green Belts [10]

New positions created to staff Lean Six Sigma efforts

Champions: A Champion is an executive-level manager who has the responsibility for managing and guiding Lean Six Sigma efforts—and for making sure those efforts support and drive corporate priorities. Every organization should have a Champion reporting directly to the CEO or President. Large organizations may also have divisional or business unit Champions who report directly to the person in charge of that unit.

Black Belts: These are company employees who receive a minimum of 4 to 5 weeks of training on leadership and problem solving. They usually work full-time on Lean Six Sigma, though in some organizations they may only be part-time. They are responsible for leading or coaching project teams, and for delivering results on the selected projects.

Master Black Belts: These are Black Belts who have gone on to receive advanced training in more sophisticated problem-solving techniques. They also will have led a number of project teams and have a proven track record of delivering results. Their responsibilities include training and coaching Black Belts, monitoring team progress, and aiding teams as needed.

Staff who maintain their regular jobs but whose responsibilities expand to include Lean Six Sigma:

CEO & executives: The Chief Executive Officer and other executives determine whether a company will adopt Lean Six Sigma. And they are ultimately responsible

for setting corporate goals that will shape Lean Six Sigma priorities. They are also responsible for regularly monitoring and guiding how Lean Six Sigma resources are used.

Business unit managers: Every company is made up of different business units—departments, locations, plants, etc. In some, the leaders of these business units are Presidents, in others, they are Vice Presidents. But no matter what the title, these Business Unit managers need to work closely with the Champion. Together, they use the unit’s goals to define criteria for selecting projects. The final decisions about project targets belong to the Business Unit manager, because he or she will be accountable to the CEO for meeting annual goals.

Line managers/process owners: Line managers are the people who “own” the processes that will be improved by Lean Six Sigma. That is, they are responsible for authorizing changes in process procedures. (For that reason, some companies call these people Process Owners.) They are responsible for approving time for staff to attend training, serve on project teams, and so on. Support from line management is therefore critical to Lean Six Sigma success. When projects are launched in their work area, the line managers usually also serve as project sponsors. In that role, they are responsible for monitoring the team’s progress, providing support as needed, and sustaining the business results delivered by the project team.

Green Belts/Yellow Belts/White Belts/Team members: These can be anyone in the organization who receives some level of awareness education or skill training in Lean Six Sigma. They usually maintain their regular jobs, but work part-time on projects in their work areas.

Typical training programs

Just like the Lean Six Sigma efforts themselves, training programs differ greatly from organization to organization. Typical levels of training include [10]:

1. **An awareness course** (*White Belt training*): A brief course, often just a day or two long. The goal is to help people get familiar with Lean Six Sigma language and concepts. Project participation is usually *not* a requirement.
2. **An introductory methods/tools course** (*Yellow or Green Belt training*): The next level up is a course where people get to practice using the improvement

methods and techniques. The training can last anywhere from one to two weeks. The Yellow Belt is intermediate between White and Green. The difference is that a Yellow Belt course is usually a bit shorter than Green Belt training, and people are required only to *participate* on projects. Most companies require people to *lead* projects to become a Green Belt.

3. **A skill-building tools/methods course ([Black Belt training](#)):** Black Belts are the core of the Lean Six Sigma support structure. In some companies they lead projects; in others, they serve as coaches and resources to several projects at a time. (See sidebar, below, for a description of a typical Black Belt course.)
4. **Advanced training in one or more specialties (*Master Black Belt or enrichment courses*):** There are a handful of sophisticated Lean and Six Sigma tools that are extremely valuable in some limited circumstances. It doesn't pay to train every Black Belt on them because they won't be needed as often as the more general Lean Six Sigma tools. Such skills are often covered either as part of Master Black Belt certification or in specialized enrichment classes available to Black Belts.

In conclusion, Lean Six Sigma is a discipline that has learned from past mistakes. And one of the mistakes made by previous improvement methodologies was to ignore management support. Initially, a lot of managers find themselves thinking that Lean Six Sigma efforts are somehow “stealing resources” that they would rather devote to the “real work.” But once they see the kinds of rapid and sustainable gains earned when well-trained people work on high- priority projects (linked to the managers' business goals), they quickly become enthusiastic supporters of training and education.

In Lean Six Sigma companies, this focus on systems and processes begins at the top. For example, when Lou Giuliano, the CEO of ITT Industries, goes into one of his business units, his first questions for the managers are about what they are doing with their Lean Six Sigma projects—because he knows that it's through these efforts that the company will be able to meet its aggressive goals. This clearly focuses management on process improvement.

II.2.8 Lean Six Sigma Approaches in the Literature

The concept of combining Lean manufacturing and Six Sigma principles began in the middle to late 1990's, and has quickly taken hold. There are many examples of manufacturing companies implementing a combined effort of Lean and Six Sigma.

An early example, starting in 1997 was by an aircraft-engine-controls firm, BAE Systems Controls, in Fort Wayne, Indiana. They blended Lean-manufacturing principles with Six Sigma quality tools. Their "Lean Sigma" strategy was "designed to increase velocity, eliminate waste, minimize process variation, and secure its future in the evolving aerospace market" [15]. They started with implementing Lean initiatives and then identified a synergy between Lean and the Six Sigma quality program that had been launched while the company was a part of General Electric. BAE Systems Controls implemented the following Lean initiatives: 1) Kaizen events, 2) takt-time-driven one-piece-flow product cells, 3) Kanban pull system and point-of-use storage bins on the plant floor, 4) Lean production cells, 5) mistake proofing, and 3) use of a multi-skilled workforce. As part of the Six Sigma program, they implemented statistical methods and team leadership with the use of Black Belts. The primary focus of BAE's Six Sigma program was to reduce variation within their processes. To blend Lean and Six Sigma, they incorporated the Six Sigma Black Belts within the Kaizen teams. The Black Belts used the statistical techniques to help solve problems. They found that the Six Sigma tools helped to generate the data needed to justify major improvements, such as equipment upgrades. They also used cause and effect analysis to understand the underlying causes of the process variation that allowed the Lean improvements. In BAE Systems Control's implementation of Lean Six Sigma, they improved productivity by 97% and customer lead time by 90%. Their value-added productivity increased 112% in five years, work in process was reduced by 70%, product reliability improved by 300%, and there were zero lost workdays in 1999 [16].

Another early innovator combining Lean and Six Sigma was Maytag Corporation. It implemented Lean Sigma in 1999. They designed a new production line using the concepts of Lean and Six Sigma. Maytag reduced utilized floor space to one third of that used by Maytag's other product lines. Maytag also cut production costs by 55%. Their Lean sigma effort helped Maytag to achieve savings worth millions of dollars [16].

TBM Consulting Group implemented their Lean Sigma methodology at Pease Industries [17]. The basic approach included first implementing Lean principles. The consultants established one-piece flow, eliminated waste and redeployed operators no longer needed on the line. Once the hidden factory or waste was exposed, they implemented Six Sigma principles to reduce variation and improve quality.

The company performed a Lean Sigma Event as follows: 1) a one day Measure phase applying a quality map, cause and effect analysis, Pareto analysis and a Chi Square analysis on defects, 2) A two day Analyze and Improve phase using Comparative Analysis, quality tools and hypothesis testing, Jidoka-Failure Mode and Effect Analysis (FMEA), Poka-Yoke (mistake proofing) and Realistic Tolerancing, 3) A 30-day Control follow-up phase. They found that they were able to complete projects faster, and generate quality with less capital. They also identified the root cause of a problem instead of implementing a \$30,000 solution to a perceived problem. Lean Sigma has saved Pease Industries over a million dollars a year in scrap and manpower reductions. In another Lean Sigma implementation, TBM Consulting Group first performed Lean Sigma training. The project champions received one week of training. The Black Belts received four weeks of Lean Sigma training. The Green Belts received two weeks of training, plus on-going mentoring. The Lean Sigma improvement process of Measure, Analyze, Improve and Control (MAIC) was used to implement Lean Sigma project. The typical MAIC project timeline consisted of 1) a Measure phase including a four to five day Kaizen event, 2) Analyze and Improve phase with a 5 day Kaizen event, and 3) a Control phase with a 30 day follow up. The improvement process also includes a few weeks between each phase for data collection and testing. Some of the successful Lean Sigma implementations that TBM was part of achieved significant results, including: 1) capital reduction of 20 to 30% per year, 2) productivity improvement of 15 to 20% per year, and 3) quality improvement of 50% per year. In other case studies reported in the literature by Bonnie Smith the approach to Lean Sigma depends on the problem to be solved. In a Lean Sigma implementation with playground equipment manufacturer the company had implemented Lean techniques and then implemented Six Sigma when a problem arose that needed Six Sigma Quality techniques. Another TBM Consulting Group Lean Sigma implementation with a commercial refrigeration equipment manufacturer used the best of Lean and Six Sigma [18].

Goyal presents how Lean Six Sigma was implemented in a company that converted paper documents to electronic copies [18]. The company first improved the consistency of the product quality through the application of Six Sigma quality tools. They used a modified DMAIC improvement process. They first performed a Define and Measure phase. Brainstorming was used to identify over 30 problems. They then affinitized the problems into two categories and then prioritized the problems using a weighted voting consensus system. A second brainstorming session further defined the problems. They then collected data to measure the problem. The second phase performed was the Analyze phase. They flowcharted the process and identified the value added and non-value added activities. Principles of Lean manufacturing were introduced during the Analyze phase including: 1) zero waiting time, 2) zero inventory, 3) scheduling using pull techniques, 4) reducing batch sizes, and 5) line balancing. They used Pareto Analysis within the Lean solutions. They performed an Idea Generation phase to develop an implementation plan. They performed a pilot test of the new process, and then implemented the change and checked the result. To control the processes they implemented control charts (a Six Sigma technique) and standard operating procedures (a Lean tool). The Lean Six Sigma implementation reduced the error rate by 98% when converting paper documents to electronic copies, increased productivity over 50%, reduced costs, improved quality, and improved the ability to handle peaks of input data within customer specified turnaround limits [19].

Lean Six Sigma has been implemented at Northrop Grumman, an Aerospace Company. They had already begun to implement Lean Thinking when they embarked upon their Six Sigma program. They integrated the WorkOut events (a problem solving process developed at GE) with the Lean Thinking methods and Kaizen events. They used Six Sigma's strategy and methods within their Product Teams, not as a stand-alone program. Their formal process integrated WorkOut, Kaizen and DMAIC into the Six Sigma Breakthrough WorkOut. They use subject matter experts and a Black Belt on their project team. They perform a four to five day Define/Measure phase. They then performed the Measure, Analyze and Improve phases of roughly thirty days each. The final activities included a post-WorkOut phase as the Control, Integrate and Realize phase. They used the Lean improvements "to change some things that are obvious and save the Six Sigma tools for the High Fruit – the harder problems" [20]. They also used Six Sigma tools to validate

proposed solutions statistically prior to implementing the solutions. Lockheed Martin Aeronautical Systems reduced costs, improved competitiveness, customer satisfaction and the first-time quality of all its manufactured goods. They had separate Lean and Six Sigma projects, depending on the objective of the project and the problem that needed to be solved [21].

Rockwell Automation Power System has used a program called Power Lean. Power Lean combines the structured problem solving and training structure of Six Sigma programs with the Lean concepts and Kaizen teams. The Power Lean approach uses value stream mapping to identify improvement opportunities and Kaizen events to implement smaller focused improvements. They used the Six Sigma problem solving structure and Black Belt leader concept to facilitate larger improvement projects and to implement Lean flow [22].

Six Sigma and Cycle Time Reduction (CTR) have been implemented together in Citibank, an international financial company. They first trained the employees in Six Sigma defect reduction and Cycle Time Reduction. They used process mapping to understand and improve processes to eliminate wasteful steps. They implemented process improvement teams and focused on customers and defects through application of Six Sigma principles and techniques. Citibank improved total customer satisfaction, improved processes and reduced process timelines through application of Six Sigma and CTR [23].

Lean Six Sigma has also been implemented in distributors. K.J. Electric, a distributor of Syracuse New York, first implemented Lean principles and then Six Sigma techniques [24]. Kaman Industrial Technologies, another distributor, implemented the Rockwell Automation Power Lean System which combines the Lean manufacturing philosophy with Kaizen and Six Sigma tools. They used the Kaizen events to develop improvement plans. Their Lean Six Sigma implementation reduced process steps by up to 50 percent, improved throughput and cycle time and reduced the use of resources [25]. In “The Perfect Engine” Anand Sharma and Patricia E. Moody suggest that most companies first implement Lean principles and then implement Six Sigma techniques [26].

In the book, “Leaning into Six Sigma”, the authors describe implementing Lean Six Sigma in a manufacturer first by applying Lean principles, such as: first impressions, basic housekeeping, work cells, and preventive maintenance [27]. The manufacturer then applied Six Sigma tools such as: gage repeatability and

reproducibility, Design of Experiments and Analysis of Variance. Most of the companies reviewed in the recent literature also approach the application of Lean Six Sigma first by implementing Lean principles and tools and then, once the waste is exposed, variation is reduced and quality is improved by implementing Six Sigma tools [28].

There are a few applications in the literature where the two methodologies are closely integrated into one methodology. In Michael L. George's "Lean Six Sigma, Combining Quality with Lean Speed", the recommended methodology follows the Six Sigma DMAIC improvement process, interspersing Lean and Six Sigma tools within the framework [10]. TBM Consulting Group's Lean Sigma methodology uses the Lean Kaizen improvement tool coupled with the Six Sigma DMAIC improvement process to shorten the timeframe of a typical Six Sigma implementation of four to six months to one to two months [29].

In an article by Paul A. Keller, he suggests defining a Six Sigma project to implement Pull scheduling, a Lean tool. The DMAIC improvement process would be used to implement Lean concepts [29]. In reviewing the literature the two approaches to implementing Lean Six Sigma can be summarized as follows:

- 1) Using Lean and Six Sigma as complementary approaches. First implement Lean Thinking to identify and eliminate waste through the use of Kaizen events, then implement Six Sigma to reduce variation and improve quality using the DMAIC improvement process. Within this approach, Lean Kaizen and other Lean tools are typically applied on less complex problems, while Six Sigma and statistical tools are applied on more complex problems.
- 2) Use the Six Sigma DMAIC improvement process framework in a more integrated approach with Lean Thinking to focus on cycle time reduction and Lean tools and projects. The DMAIC improvement process is used to implement Lean projects, such as pull scheduling, set up reduction or cellular manufacturing.

In literature, there are several studies about lean six sigma can be listed as follows;

Table II.8: Literature studies according to sectors

the author and year	sector	subject
Kandebo, 1999 [30]	aircraft industry	application- reducing defects
Sheridan, 2000 [31]	aircraft industry	application- reducing costs
Bossert and Walker, 2002 [32]	service industry	applicability of lean six sigma in service industry
Dubai Quality Group, 2003 [33]	white goods industry	application- design of assembly line
Pojasek, 2003 [34]	general	comparison of six sigma, lean management, and system approaches
Brett ve Queen, 2005[35]	information management	applicability of lean six sigma in information technology industry
Furterer and Elshennawy, 2005 [36]	public sector	application- improvement of finances process
Marti, 2005 [37]	pharmaceutical industry	application- reducing clinical test costs
Bendell, 2005 [38]	general	comparison of six sigma, lean management, and ISO 9001:2000
Kumar and et.al.,2006 [39]	iron casting industry	application- reducing the effects during the iron casting process
Bertles, 2006	insurance	application- reducing costs
Hesselschwerdt, 2006	marketing	applicability of lean six sigma in marketing
D'Angelo et al.,2007 [40]	service industry	six sigma and quality improvement
Antony et al.,2008 [41]	general	application of lean six sigma

CHAPTER III:

CASE STUDY IN AN ELECTRICAL COMPANY

Lean Six Sigma is currently used in several industries, especially in automotive industry. This chapter represents an applied study with using the lean six sigma methodology for the product delivery time performed in Schneider Electric Company.

III.1 COMPANY OVERVIEW

Schneider Electric is a major international electrical company group in electricity market. From 1836 to today, starting from its roots in the iron and steel industry, heavy machinery, and ship building, it moved into electricity and automation management. After 170 years of history, the company has become today the solution provider that will help to make the most of your energy. Period of organic growth, positioning itself in new market segments: UPS (uninterruptible power supply), movement control, building automation and security through acquisitions, becoming the global specialist in energy management [42].

In the Energy & Infrastructure market, their products and services solutions cover:

- Processes control and supervision
- Power supply & distribution
- Energy monitoring and control
- Utility management (lighting, ventilation, elevators, intruder alert, etc.)
- Smart electrical networks management
- Single site or multi-site production data management
- Critical power
- Offer prepayment systems that bring electricity to disadvantaged customers

They innovate to imagine and develop the best energy management solution for every market and every customer in the scope of company innovation and R&D strategy. Their objective is to develop solutions that not only optimize efficiency and reduce costs, but also deliver increased simplicity, ease of use, and environmental benefit in globally. These new responses to the issues of energy efficiency and the emerging Smart Grid incorporate high technology products, services, and software.

This project is carried out in Izmir plant of Schneider Electric Company is 15000 m² where has ISO 9001:2000 Quality management system.

III.2 OBJECTIVES OF THE APPLIED STUDY

This project is applied for the aim of decrease delivery time of SM6-36 (range composed of metal-enclosed switchgear modular) from 6 weeks to 4 weeks in average from customer order to ready for deliver. Since shorter delivery is one of the main customer needs and has big potential of order increase, decreasing delivery time of this product is aimed for increasing customer satisfaction.

SM6-36 is a range composed of metal-enclosed switchgear modular units up to 36 kV, easily adaptable to your specific requirements: containing circuit breaker using SF6 breaking technology, switch-disconnector, fuse-switch, rated current from 400 to 1250 A, short-circuit current up to 25 kA, internal arc withstand. In scope of control, monitoring and protection devices: providing protection of your installations, continuity of electrical supply and reducing downtime, sepam relays, a range designed with telecontrol in mind.

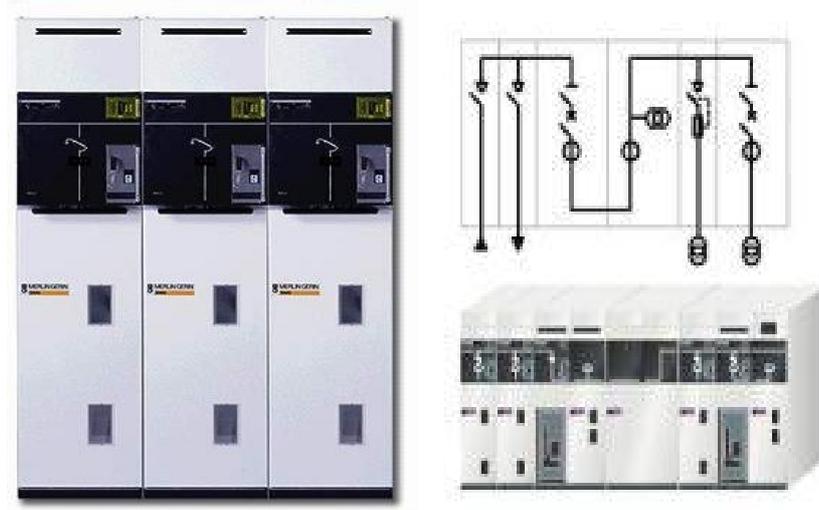


Figure III.1: The pictures of SM6-36

Figure III.1 shows the picture of SM6-36. The SM6 range is a comprehensive and upgradable offer of highly reliable. Air Insulated modular units for all your MV secondary underground distribution application. This product is combining flexibility to simplicity of installation and operation. SM6, which is in MV section in MV/LV transformer substations in public distribution systems, is demanded from MV consumer or distribution substations from 25 to 36 kV.

This project is applied throughout 6 months using with lean six sigma practices, e.g DMAIC, Kanban, lean manufacturing. In the following section, it is focused on DMAIC (Define, Measure, Analyze, Improvement, and Control) cycle applied step by step in this lean six sigma project.

This project is carried out with lead of green belt. Green belts generally work at part time, and run DMAIC based projects. Green belt is a competence or a skill rather than a job or position. They receive sufficient training in order to be able to run projects that delivery quantifiable benefit using the DMAIC model. They are required to commit to running 2 projects before they begin training. Once they have successfully completed their training and delivered 2 projects they will be certified as competent Green Belts.

III.3 STEPS OF THE APPLIED STUDY

This lean six sigma project is carried out with using DMAIC. Steps of this project are explained as follows individually;

The route of this study is summarized in the Figure III.2 as follows.

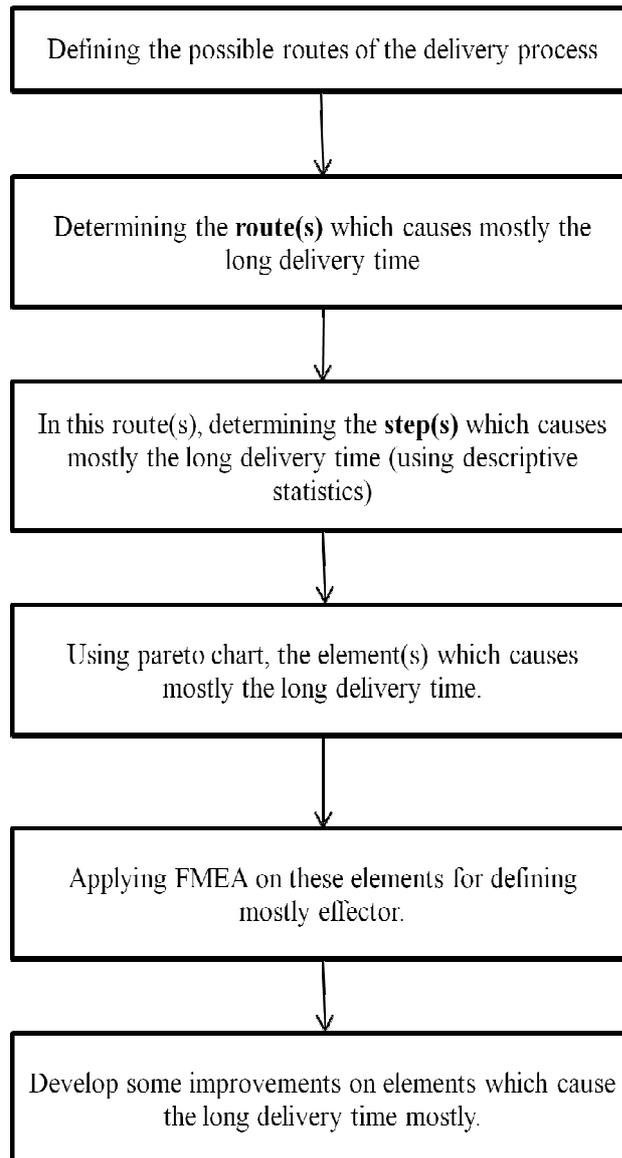


Figure III.2: The route of this study

III.3.1 Define

The purpose of this first stage of the DMAIC process is for a team and its sponsors to agree on what the project is. In this stage, it consists;

- Discussing the project charter as a team.
- Getting customer data.
- Reviewing existing data about the process or problem.
- Drafting a high-level map of the process.
- Setting up a plan and guidelines for your team.

In this project, Define phase includes that problem statement; measurable goals/objectives are defined. In addition to; business case, project scope, roles/resources, schedules/deliverables are determined in details.

After this project, it is predicted that advance payment costs, risks, other related costs will decrease, besides customer benefits and capacity will increase. The key success factors are determined as support from sponsor, belief and high contribution of members to the project. Constraints and risks of the project are assumed as feedback from the customer may not be reliable, order increase due to result of project improvement may not be measured easily. Parameters of the project are stated as ordering, engineering, planning, procurement, assembly, quality. All of the above mentioned issues about the projects are detailed in the project charter, which is any type of table. Besides the above mentioned terms about the project, the project leader, team members and support members of the project are assigned in project charter.

The tool for creating a high-level map of the process is called SIPOC, as figured (Table III.1) in this stage. Project team in the company that aim to decrease delivery time of SM6, firstly created SIPOC diagram to identify the basic elements of the process they were supposed to study. SIPOC which stands for;

Suppliers: the individuals or groups who provide whatever is worked on in the process (information, forms, material)

Input: the information or material provided

Process: the steps used to do the work

Output: the product, service, or information being sent to the customer

Customers: the next step in the process, or the final (external) customers

SIPOC diagrams are very useful for visually representing the basic elements of a process under study (see Table III.1). But they don't really help the team understand what needs to be changed in a process. For that, they need more detailed process maps.

One type of process map used frequently in Lean Six Sigma projects is called a value stream map. These maps only show the process flow (See Figure III.2).

Table III.1 :SIPOC of the project

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
<ul style="list-style-type: none"> ▪ Customers (end users, contractors, Partners, MV distributors ▪ Marketing dept. ▪ Commercial Dept ▪ Core Unit ▪ Product Manager ▪ Standard Institudes ▪ Quality Dept ▪ Software Producers ▪ Computer producers ▪ Subcontractors ▪ Assembly tool producers ▪ CTC, PCR ▪ Renkler, Akimsan ▪ HR ▪ General Services ▪ Transport. Tool producers ▪ Measuring Tool Producers 	<ul style="list-style-type: none"> ▪ Order ▪ Contract ▪ SOC ▪ Sales policy (price list, discount, premium) ▪ Technical Document ▪ Transfer Files ▪ Technical Instructions ▪ Design Tables (Door dxf, Standart labels, drawings) ▪ Standarts ▪ Internal Forms ▪ Softwares (SAP, Haendel, Auto-CAD) ▪ Communication Tools ▪ Assembly tools ▪ Material (Level-T, CT-PT, Local Electricals Parts, Imported Parts, Metal Parts) ▪ Labor ▪ Power (Electricity, compressed air) ▪ Measuring tools ▪ Transportation tools 	<ul style="list-style-type: none"> ▪ Order Receive ▪ Drawings & Other Document ▪ Procurement ▪ Assembly ▪ FQC ▪ Acceptance ▪ Delivery ▪ Invoicing 	<ul style="list-style-type: none"> ▪ On time and good quality 	<ul style="list-style-type: none"> ▪ End users ▪ Contractors (Electric) ▪ Contractors (Main) ▪ Partners ▪ MV Distributors

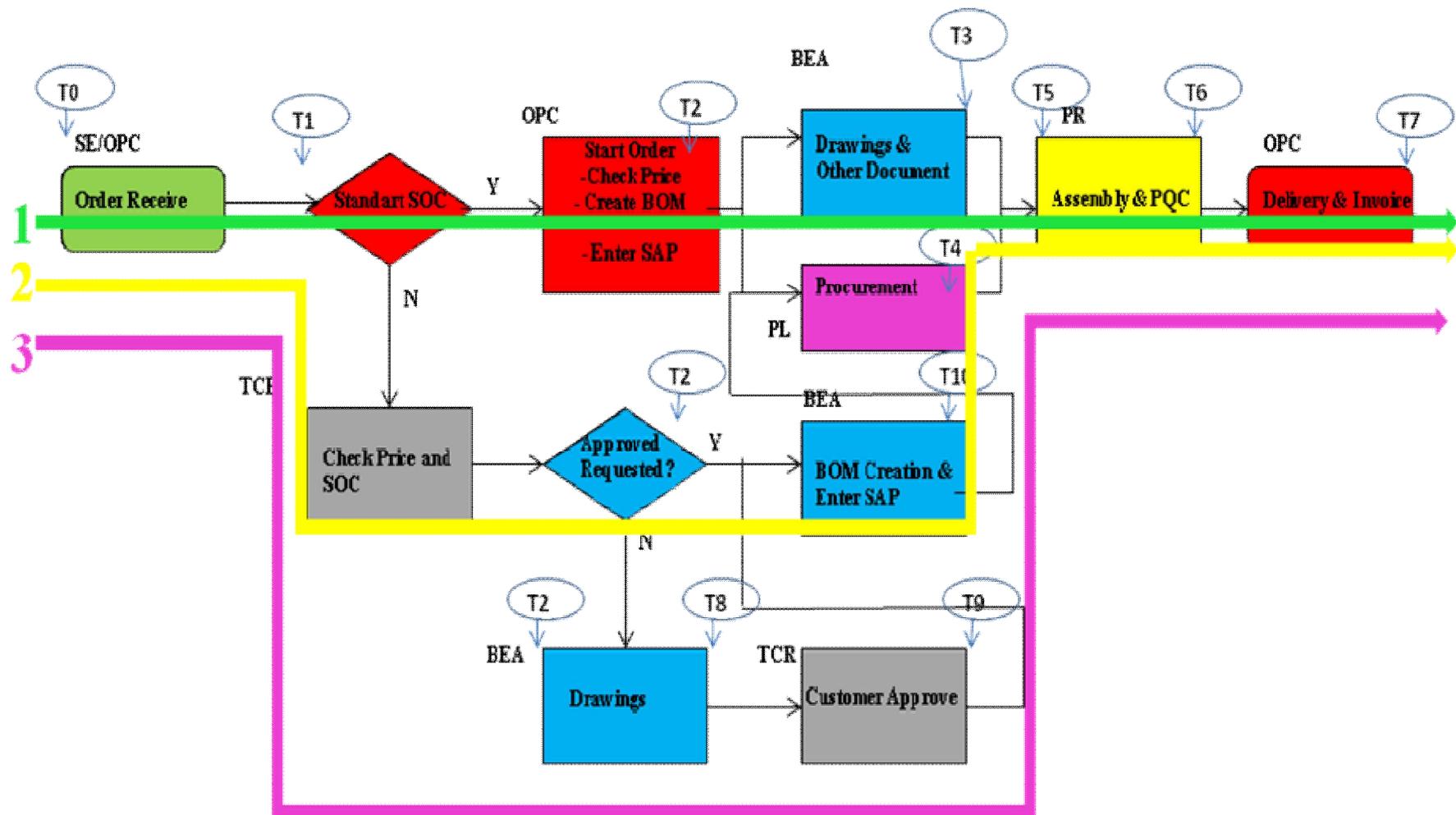


Figure III.3: Process Flow Chart for Delivery time

1, 2, 3 : The possible route of the process

T1 to T10 : Dates to be measured from - SAP (no specific report, needs to use many different reports and combine datas, dates may not be true)
 - or MANUAL (not all datas for the past, action already started)

The above process flow chart which detailed analysis of the process and clarify the steps in a process, captures decision points, complexity. This chart demonstrates three possible routes of the delivery of SM6-36. If standard SOC is not valid (for route 2 and 3), price and SOC which exists should be checked.

The Standards Oversight Council (SOC) is responsible for overseeing the process used to develop and maintain technical standards for urban and rural soil and water conservation practices. In other words, the Council is the “gatekeeper” for the technical standards process. The Standards Oversight Council is created to facilitate a technical, rather than legal and/or political, process.

If price and SOC are not approved, new drawings and customer approve should be done. After customers approve and new drawings is done, or check price and SOC is accepted, BOM’s will be created and these will be entered in SAP. The next steps are procurement, assembly line (production) and finally delivery to customers and invoice respectively.

As far as it is expected, if the amount of steps of the process increases, then delivery time will increase. %57,5 of the total quantity of delivery belongs to route 1 and the remaining part (%42,5) belongs to total route 2 and 3.

Actually, route 1 presented standard order which consist standard SOC, price, BOM and generally procurement that’s why the time of delivery for route 1 is less than other routes represents nonstandard orders.

The below tables shows that route 1 has less delivery time than route 2 and 3. It can be considered that for achieving the target delivery time, route 1 should be applied more than other routes. The route 1 represents standard order process; beside route 2 and 3 represent non-standard order process.

This project aims to decrease delivery time for non-standard orders, meanwhile it is expected that route 2 and route 3 will be improved to minimize the delivery time of the product.

Table III.2 The percentage of routes

Route	Quantity (%)	Delivery (mean-week)	St. Dev.
1	57,5	4,3	1,8
2 and 3	42,5	6,3	2

As it is seen in the Table III.2 that delivery time of route 1 is so nearly to target time with the value of 4,3. If the project team achieves to increase to the quantity of route 1 in overall orders, the target value of delivery time will be gotten.

III.3.2 Measure

In Measure phase consists process mapping, and value & non-value added in the process. (“Process maps” are one type of improvement tool used often in DMAIC. they are used to help establish the project boundaries.)

Value added refers to a process or step within a process which transforms work in progress into much more valuable goods and services to customers downstream. It aims at increasing its value per unit of material. In the above tables, the actors are evaluated according to their value added in different types. After these calculation, general percentage of the system is revealed as 27,8 %.

Table III.3: Value Added & Non value Added for Process

Actor	Type	Total Step	Value Added	Non value added	&Value added %
BEA	Process	22	9	13	40,9
CUS	Process	1	1		100,0
OPC	Process	13	5	8	38,5
PL	Process	39	8	31	20,5
PR	Process	24	8	16	33,3
SE	Process	20	7	13	35,0
TCR	Process	11	4	7	36,4
Total	Process	130	42	88	32,3

In Table III.3, value & non value added for process are given. The total percentage of value added in the process is 32,3 %.

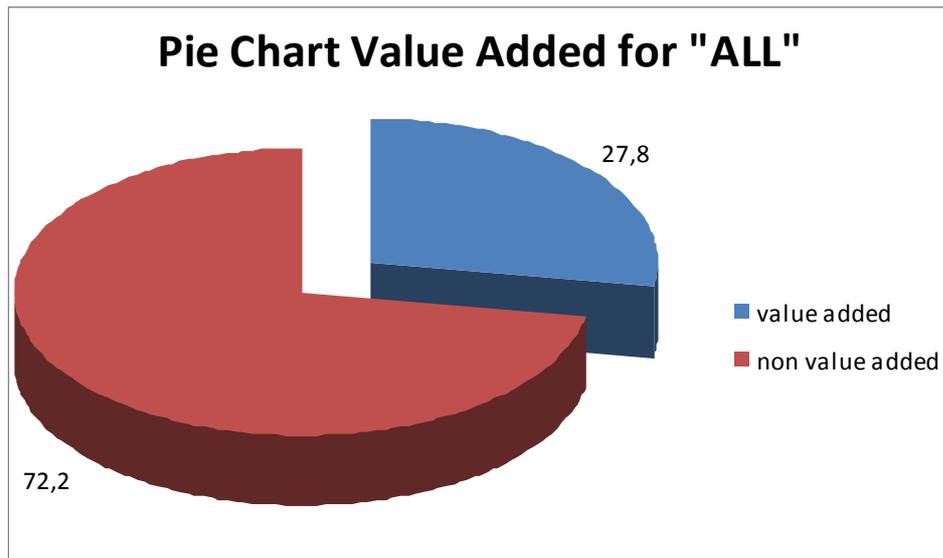


Figure III.4: Pie chart of value & non-value added

In Figure III.3, value & non value added for overall are given. The total percentage of value added is 27,8%.

Until this part, value and non-value added are evaluated according to progression type as process, decision, and terminator. Now, let us see percentage level of value added according to routes as follows;

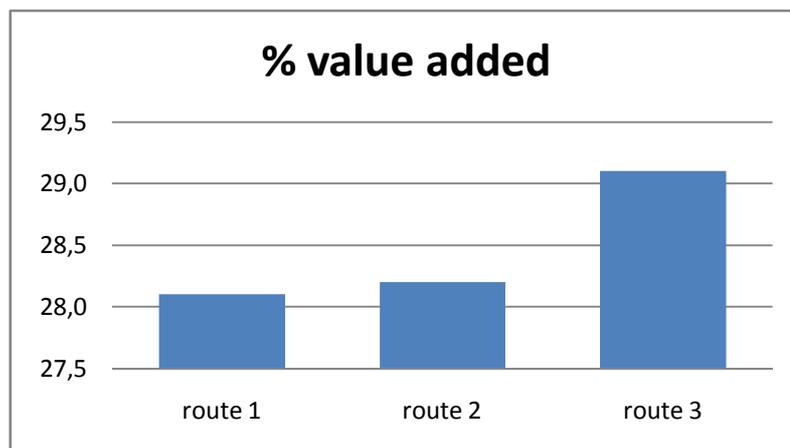


Figure III.5: Value & Non-value added for routes

Figure III.4 shows the percentage of value added for all routes. The highest percentage level is 29,1% for route 3, and the smallest is 28,1% for route 1. However, it can be said exactly that the differences between routes according to value added level is slightly.

Table III.6: Percentage of Value Added Steps for Routes

Route	Total Number of Step	Number of Step Value Added	Number of Step Non Value Added	Percentage of Value Added Steps
1	121	34	87	28,1
2	124	35	89	28,2
3	134	39	95	29,1

To create a leaner process, team members should also analyze the worker's explanations and eliminate non-value added steps throughout the project.

After the measurement in main process steps (refers to Figure III.2), several descriptive statistics are applied as follows (see in Table III.7); The objective of this measurement is to carry out the distribution of lead time during the steps.

Table III.7: Descriptive statistics for main steps of process

Variable	N	N*	Mean	Median	TrMean	StDev
T1-T0	180	3	3,361	2,000	2,778	4,258
T2-T1 (R1)	113	70	1,310	0,000	0,901	2,567
T3-T2 (R1)	108	75	18,48	10,00	17,01	19,15
T4-T2 (R1)	112	71	27,71	26,50	26,67	20,86
T5-Max (T3, t4)	141	42	3,206	1,000	2,803	7,355
T6-T5	140	43	8,786	7,000	8,135	6,595
T7-T6	134	49	5,903	4,000	4,975	7,284
T6-T1	142	41	44,12	44,00	44,02	20,33
T6-T0	139	44	47,40	48,00	47,50	20,95
T2-T1 (R2)	59	124	0,542	0,000	0,189	1,813
T2-T1 (R3)	10	173	0,800	0,000	0,375	1,751
T10-T2 (R2, R3)	48	135	5,46	3,00	4,39	7,26
T4-T10 (R2, R3)	43	140	25,12	24,00	24,08	17,71
T8-T2 (R3)	2	181	10,50	10,50	10,50	12,02
T9-T8 (R3)	1	182	3,0000	3,0000	3,0000	*

The highest time of the steps in the process is T4-T2 (R1) route which is procurement. According to this result, the project focused on the procurement processes of SM6-36 in the delivery process for decreasing delivery time that's why it is the most important step of delivery of the product.

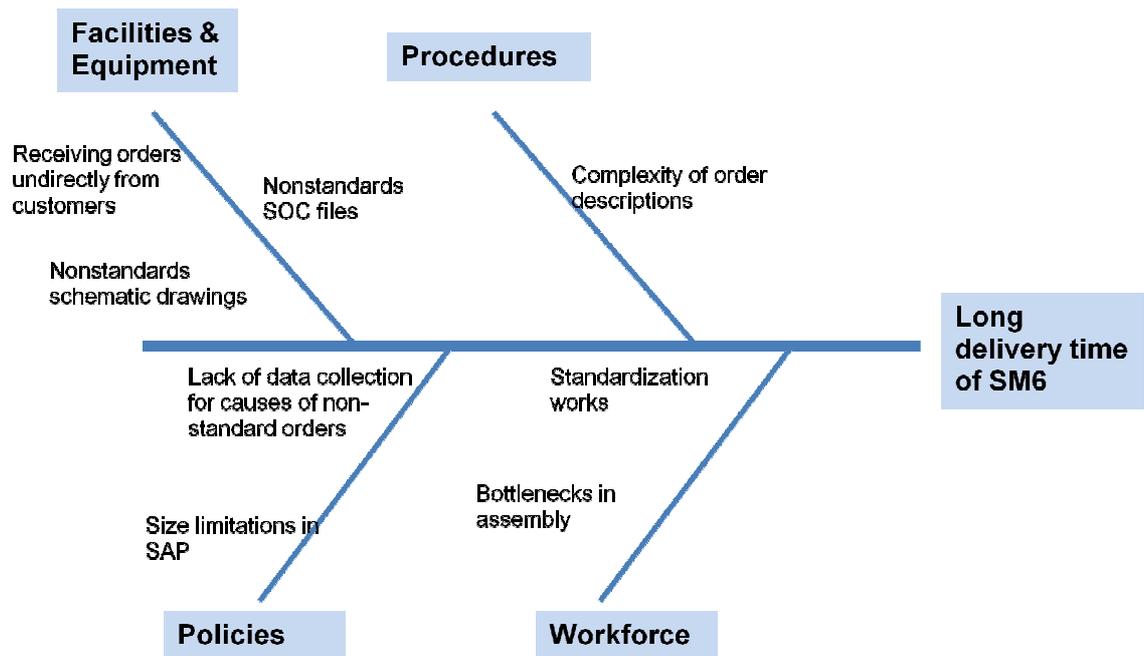


Figure III.6: Fishbone of long delivery time of SM6

The possible reasons of long delivery time of SM6-36 are seen in Figure III.6. Basic effects are equipment, procedure, policies, workforce which consist receiving orders indirectly from customers, non standards schematic drawings, and also non standards SOC files, complexity of order descriptions, lack of data collection for causes of non-standard orders, size limitations in SAP, standardization works and bottlenecks in assembly, respectively.

As it is seen that, nonstandard orders or procedures cause to get longer delivery time of SM6-36.

In Figure III.7, real and target value of delivery time of SM6-36 products for a month are given. Again, the most important time value is measured during procurement and drawings process. That's why this project team will focus on the procurement process and also whether existence of any nonstandard procurement.

Because they include data, value stream maps can help teams pick out specific points in the process that have problems such as long wait times or lots of errors

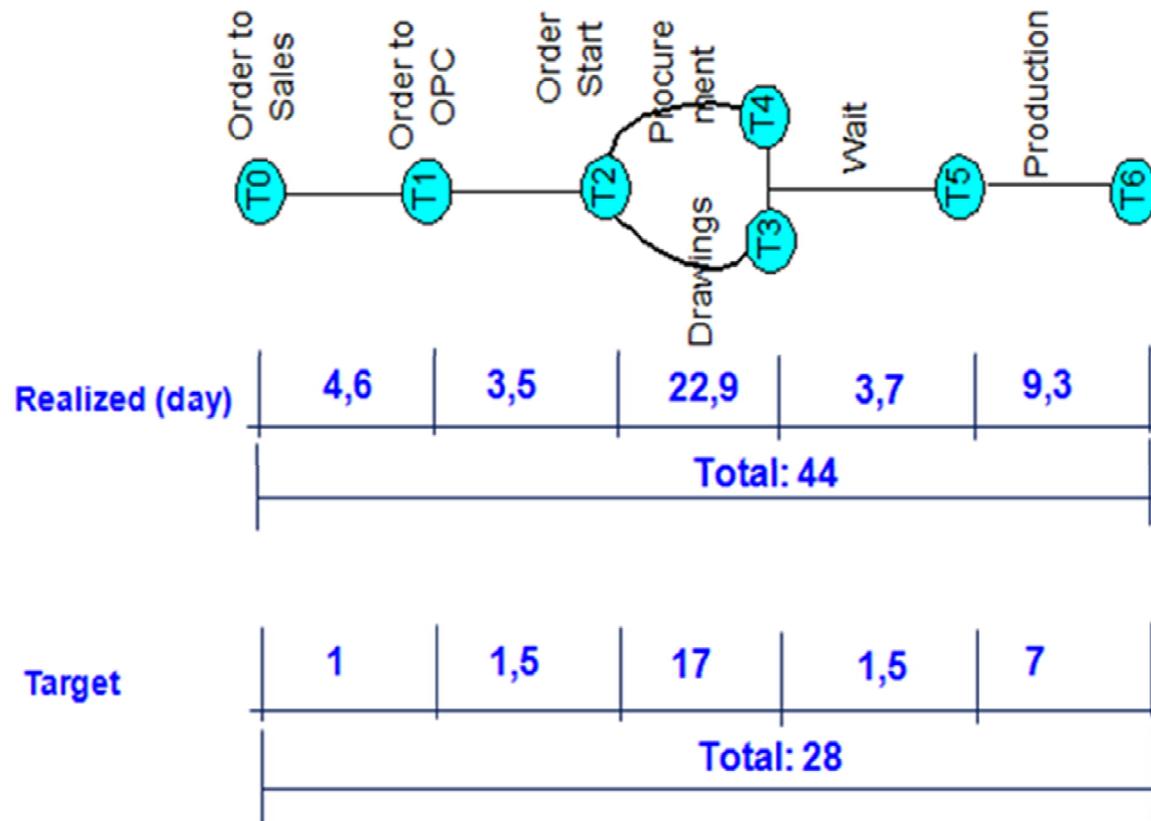


Figure III.7: Real and Target Value of the Main Process Steps (only for a month)

III.3.3 Analyze

The purpose of the Analyze phase is to make sense of all the information and data collected in Measure, and to use that data to confirm the source of delays, waste, and poor quality. In this project for analyze phase, pareto chart is figured for non-standard orders.

A Pareto chart is a graphical representation that displays data in order of priority. It can be a powerful tool for identifying the relative importance of causes, most of which arise from only a few of the processes, hence the 80:20 rule. Pareto Analysis is used to focus problem solving activities, so that areas creating most of the issues and difficulties are addressed first.

In this project, CT, Relay, Relay accessories, Voltage level, VT Action are the sources of %80 of the results (see in Figure III.8).

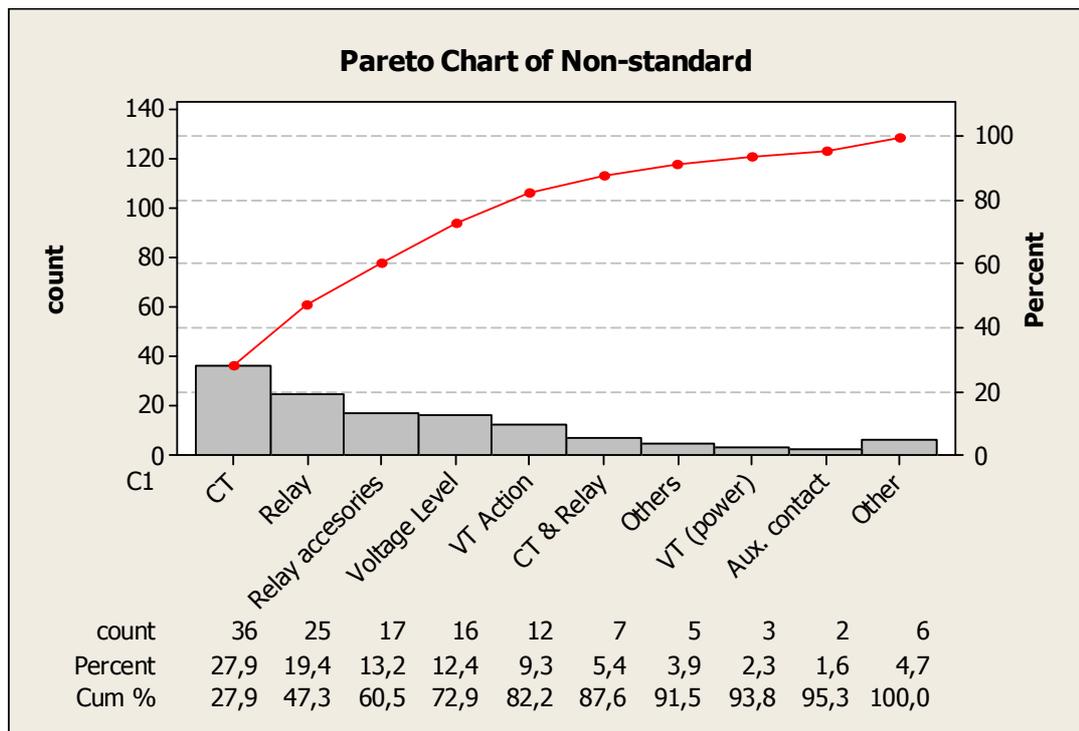


Figure III.8: Pareto Chart of non-standard orders

CT: current transformer
CB: circuit breaker

VT: voltage transformer
CTC: current transducer

In Table III.8; subcomponents of CT, Relay, Relay accessories, Voltage level, VT Action are listed and they are scored according to the severity, occurrence and detection.

FMEA (Failure Mode and Effect Analyze) was implemented on Relay, Relay accessories, Voltage level, VT Action in order to determine the reason affected on the result and to take actions according to the result of FMEA.

RPN is calculated by multiply occurrence, severity, detection scores. A severity evaluation criterion depends on customer effect and manufacturing/assembly effect. Detection scores are given according to ability of control of any effect. Occurrence evaluation criteria depend on the probability of failure of an effect. Current transformer and relay accessories have the high RPN levels; as a result the related improvements are done for these materials. If these are purchased from non-stock such as subcontractors, this process should be accelerated that it is decided. Relay, low operating voltage and VT addition have low RPNs, so there is no action taken to improve process for these materials.

Table III.8 : FMEA Analysis of Non-Standard Orders

Main Group Sub Group		Qty	SEVERITY	OCCURENCE	DETECTION	RPN	comments	result
Current Transformer		36						
	2 secondary in middle phase	28	6,00	9,00	7,00	378,00	intermediate difficulty	OK
	60/5 A 10P10 15VA 16kA	3	6,00	8,00	4,00	192,00	easy	OK
	60/5 A 0,5FS5 30VA 16kA	3	6,00	8,00	4,00	192,00	easy	OK
	10-20/5 0,5FS5 30VA 8kA	2	6,00	8,00	4,00	192,00	easy	OK
Relay		25						
	Sepam 1000+S40	3	3,00	9,00	4,00	108,00	easy	not accepted
	Sepam 1000+T40	3	3,00	9,00	4,00	108,00	easy	not accepted
	Sepam 1000+S42	3	3,00	9,00	4,00	108,00	easy	not accepted
	Sepam 1000+S41	3	3,00	9,00	4,00	108,00	easy	not accepted
Relay Accessories		17						
	ACE949-2 + CCA612	13	6,00	10,00	4,00	240,00	easy	OK
	KITSFT2841 + CCA783	2	6,00	8,00	4,00	192,00	easy	OK
	MSA141 + CCA772	2	6,00	8,00	4,00	192,00	easy	OK

Low Operating voltage	16							
Us: 6,3 KV	8	2,00	10,00	8,00	160,00	Difficult. Detailed investigation required	Not planned	
Us: 10,5 KV	3	2,00	9,00	8,00	144,00	Difficult. Detailed investigation required	Not planned	
Us: 15,8 KV	3	2,00	9,00	8,00	144,00	Difficult. Detailed investigation required	Not planned	
Us: 15 KV	2	2,00	8,00	8,00	128,00	Difficult. Detailed investigation required	Not planned	
VT Addition (DM1C)	12							
31,5/V3/0,1/V3 cl:0,5 60 VA	4	4,00	8,00	7,00	224,00	intermediate difficulty	Planned for the near future	
34,5/V3/0,1/V3 cl:0,5 60 VA	2	4,00	8,00	7,00	224,00	intermediate difficulty	Planned for the near future	

III.3.4 Improvement

The sole purpose of improve is to make changes in a process that will eliminate the defects, waste, costs, etc., that are linked to the customer need identified in the Define stage. The team must make sure that the causes they're looking at in Improve affect the problem or need defined in its charter. The changes they make must affect the causes they confirmed in Analyze.

Some actions are taken and planned as follows;

For ordering process center (OPC), receive orders directly from customers, enable OPC manage small non-standard selections.

For Project Office (BEA); develop standard schematic drawings, simplify order description, preparation to remove distribution of SOC file, collect SGL, Front views and interlookings in one drawing set, prepare new SOC file.

For Production Planning, Procurement; procurement data preparation, analyzing of data, find solutions to decrease procurement time, review supplier contracts.

For Technico-Comm. Realization (TCR); data collection for causes of non-standard orders, analyzing of data, solutions to decrease ratio in TCR route, adapting non-standards into SOC files.

For production; develop traceability of Goods supplied by customer, investigate possibility of KANBAN, adapt team leaders in terms of SAP Menus, apply KANBAN with CU.

For SAP; find solution to manage changes in OPC, find solution to label text size limitation from Elodie to SAP.

For sales; make earlier "decisions and organizations of acceptance", investigate & find an agreement to remove invoice calculation, investigate & find solutions to decrease acceptance ratio.

For works in the way of Equipment to Product; material usage reports (OPC, 6 Months) in Product tree, assignments and classifications of report items, analyzing data and realizing standardization works, optimization of mechanism, determination of bottlenecks in assembly, determination of semi-finished goods to made stock, start semi-finished assemblies.

For marketing; checking and publication of new SOC files.

According to the Figure III.9 control chart, it can be seen that the individual values (days) of delivery time of SM6-36 which takes from “order to sales” to after “production”. As it is expected that the deviation of delivery time of the process decreased after improvement and action plan. Three points of delivery time go outside the control limits before improvement. Besides, there are no points out of control after improvements.

It can be seen easily that lower and upper control limits are closer after improvement than before improvement. And distribution of delivery time values spreads with close to the average for the after improvement.

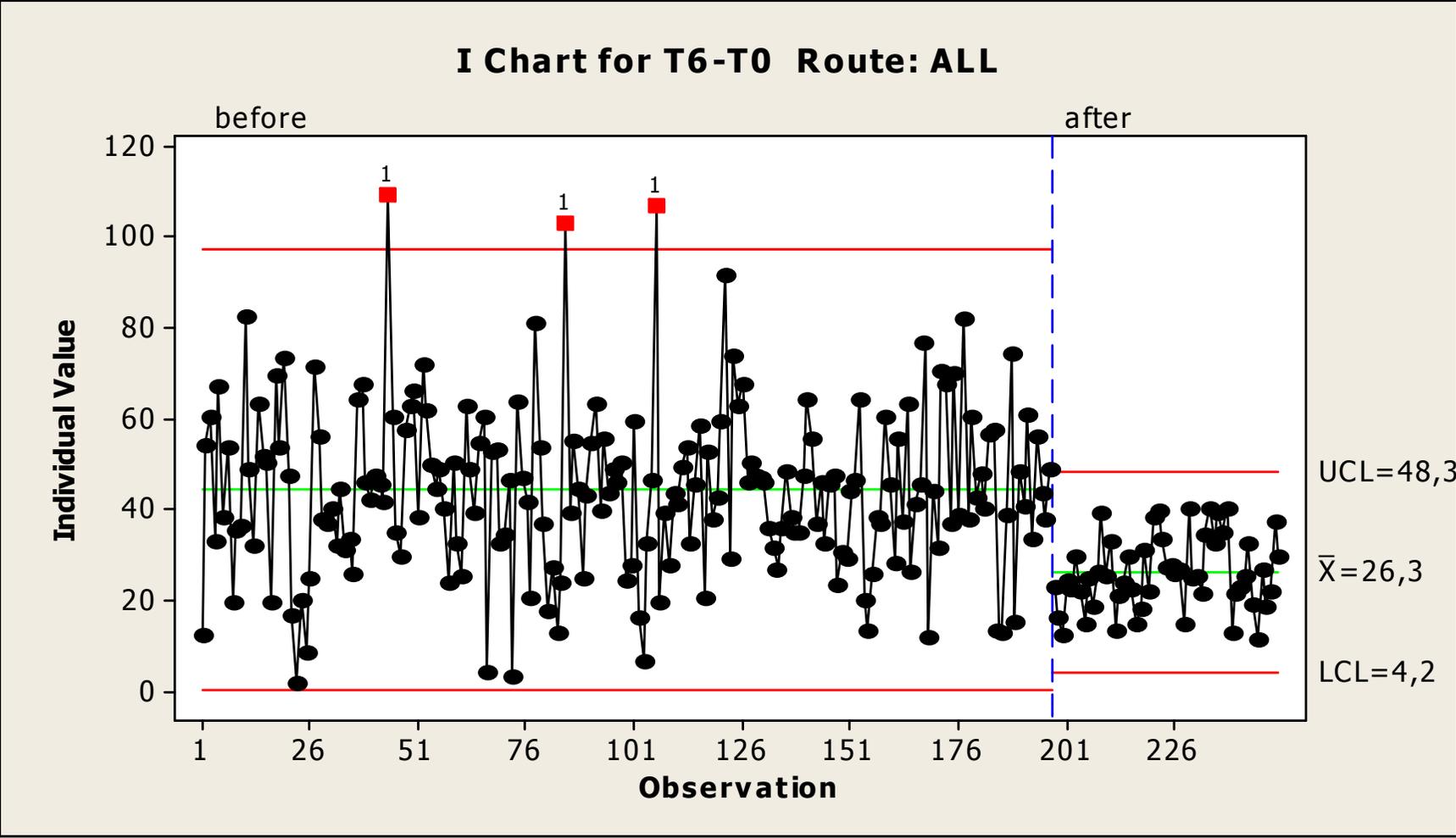


Figure III.9: Before and After Improvement of Control Chart of delivery time process

III.3.5 Control

The purpose of Control is to make sure that any gains the team makes will last. That means creating procedures and work aids that will help people do their jobs differently from now on. The team must transfer what they learned to the process owner and ensure that everyone working on the process is trained in using the new, documented procedures.

As it is expected that, variation of the process decreases after improvement as this following figure shows. So, standard deviation before improvement is higher than 'after improvement'. Target value of delivery time is achieved as 26 days (approximately 4 weeks).

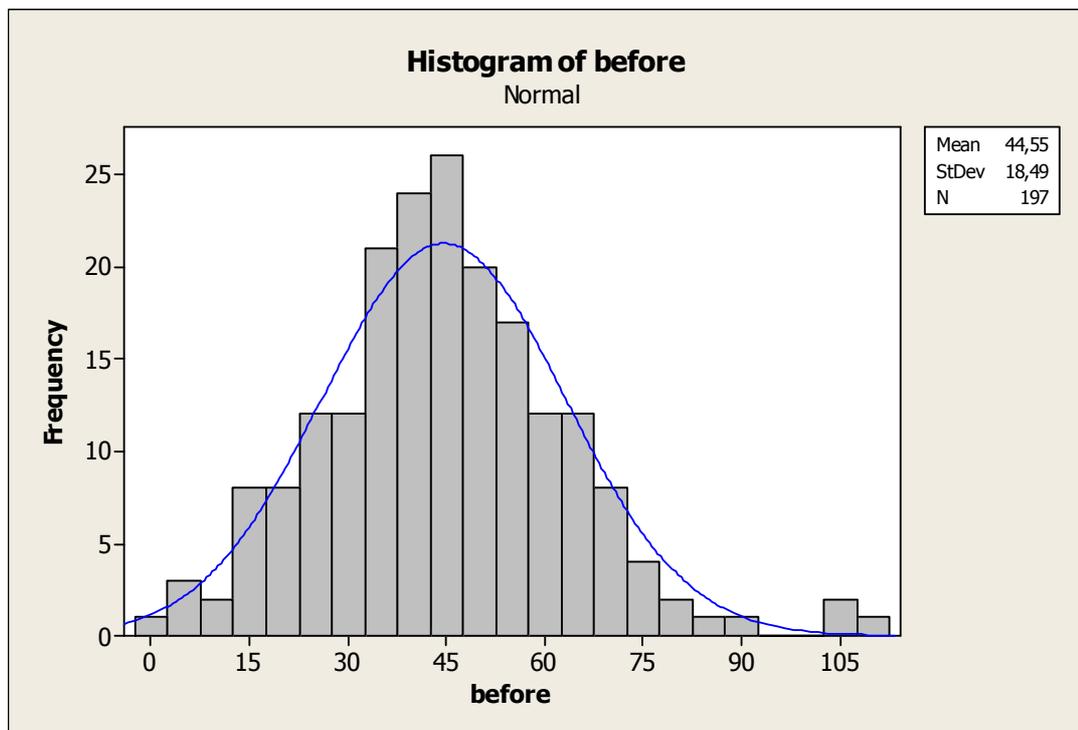


Figure III.10: The histogram of delivery time before improvement

Figure III.10 and Figure III.11 shows the histogram of values before and after improvement respectively. Width of spread of before improvement is larger than after improvement.

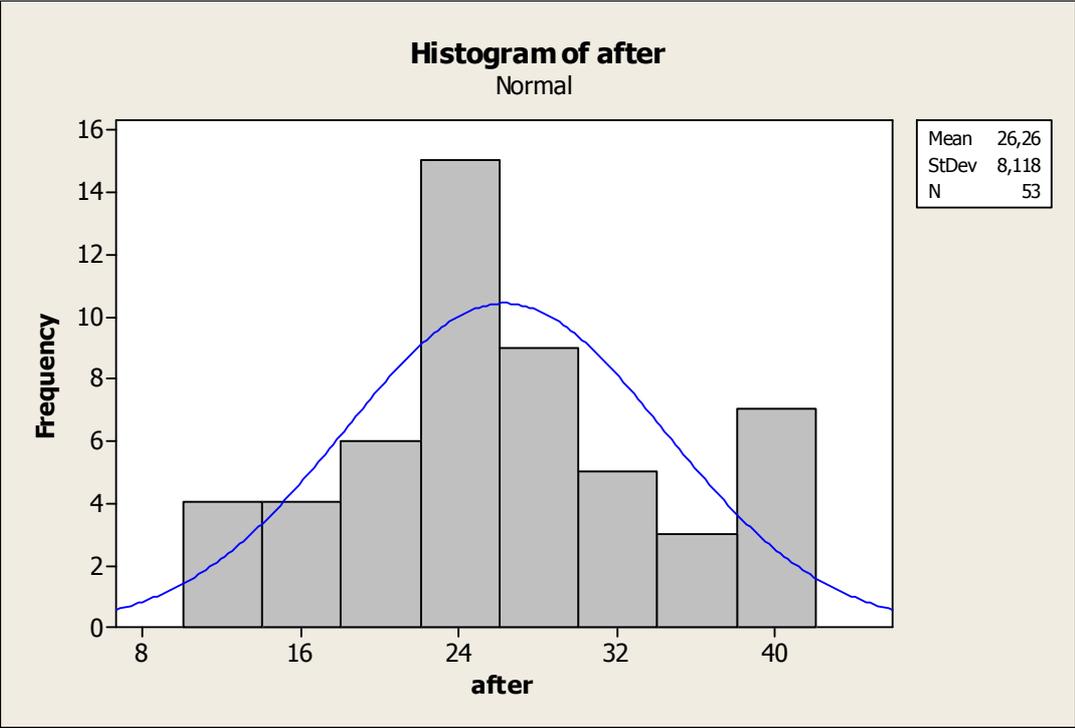


Figure III.11: The histogram of delivery time after improvement

CHAPTER IV: RESULT AND DISCUSSION

In this thesis, the main aim is to decrease delivery time of SM6-36 products from 6 weeks to 4 weeks in average from customer order to ready to deliver. Since shorter delivery time is one of the main customer needs and has big potential for order increase, the company decided to work on this project. Delivery time is also related with ordering, engineering, planning, procurement, assembly, quality, so these are assigned as perimeters of the project.

The project team used DMAIC cycle which is one of the methods of lean six sigma methodology for carrying out this project.

During the Define phase, customer benefits are determined as decrease advance payment costs, risks, other related costs, increased capacity. Key success factors are defined as support from sponsor and belief and high contribution of members to the project. In addition to, constraints and risks are brought up that feedback from customer may not be reliable, and order increase due to the result of the project improvement may not be measured easily. All the mentioned issues exist in the project charter. In this charter, team members, project leader, sponsor are also assigned, expected business benefits are mentioned. Time schedule tables are formed in the same phase.

In Define phase, SIPOC table which consists suppliers, inputs of project, process, output and customers are designated. Output is exactly strongly defined that on time and good quality of delivery to customers.

In Measure phase, process flow chart is drawn and three possible delivery routes are demonstrated in the process flow chart. First route is defined as standard order for instance standard SOC, standard procurement, drawings etc. Route 2 and 3 are assigned as nonstandard orders which have the 42% amount of total delivery. Non-standard orders cause long delivery time generally. For determining the step that has the most important effect to long delivery time, times are measured during the main process step. For instance; throughout order to sales, order to OPC, drawing, procurement, production, and delivery time are measured. After some descriptive statistics are done on these time values, step of "procurement" is

determined that the most important effect on the long delivery time not only in non-standard orders but also standard orders. As it was mentioned before, average of non-standard orders delivery time is 6 weeks besides average of standard orders delivery time 4 weeks. Therefore, actually the real target is to focus on non-standard delivery time and to decrease its level from 6 weeks to 4 weeks. For this purpose, Pareto chart for non-standard orders' procurement material is formed, and the effects that affect on the eighty percentages of the results are defined as current transformer, relay, relay accessories, voltage level, voltage transformer.

In Analyze phase, for determining the improvement on which material, Failure Mode and Effect Analysis is done with calculating RPN (Risk Priority Number). RPN is calculated as multiply occurrence, severity, detection scores. A severity evaluation criterion depends on customer effect and manufacturing/assembly effect. Detection scores are given according to ability of control of any effect. Occurrence evaluation criteria depend on the probability of failure of an effect. Current transformer and relay accessories have the high RPN levels; as a result the related improvements are done for these materials. If these are purchased from non-stock such as subcontractors, this process should be accelerated that it is decided. Relay, low operating voltage and VT addition have low RPNs, so there is no action taken to improve process for these materials.

In Improvement phase, some action plans to be taken for decreasing delivery time for ordering, projecting, production planning, especially in procurement such as receiving orders directly from customers (Implementation of direct orders from Partner (using Elodie)), simplify order description, preparation to remove distribution of SOC files, procurement data preparation, find solutions to decrease procurement time, adapting non-standard into SOC files, approved procedure in SAP has been defined, Elodie in pilot partner has been updated with the new SOC files and test orders will start first. Later it will be extended to the other partners.

For production, KANBAN applies and non-value added determined is also eliminated from whole the delivery process.

In Control phase, after and before improvement delivery time are figured in control chart. And as it seen that after improvement standard deviation decreased, and it is successfully approached to the target value of 26,26 (approximately 4 weeks).

CHAPTER V: CONCLUSION AND RECOMMENDATION

In this Lean Six Sigma projects, it was aimed to decrease delivery time o a product tree (SM6) by using DMAIC cycle in delivery process of Schneider Electric. The company's main complaint is about delivery time especially on nonstandard orders for mentioned products. Shorter delivery time is one of the main customer needs and has big potential of order increase.

The root reasons of nonstandard orders are non-stock input material, inexistence of price or SOC of material and so drawings. FMEA is used for determining the necessity about improvement on the inputs material for nonstandard orders.

To minimize the amount of nonstandard orders from customers, standardization of the delivery process should be improved with using mainly non-standard orders. In this point, a new policy should be developed from colleagues who work in any step of delivery process.

Lean Six Sigma projects touch all parts of the an organization such as cost reduction, market-share growth, cycle time reduction, error reduction, product service development, culture change, customer retention, productivity improvement, and so on. As we evaluate this project, it can be said that all these topics are aimed to gain. For instance, 4 weeks of shorter delivery time provide customer satisfaction. Because of standardization and improvement for nonstandard orders, it can be mentioned about product service development and also productivity improvement.

At the end of the lean six sigma project, it is successfully approached to target delivery time value of 26 days (approximately 4 weeks). If the company achieves this improvement for nonstandard orders to other products tree, there is wide range of customer satisfaction and benefits from orders doubtlessly.

When this lean six sigma project is evaluated, the superiorities and advantages are quite easily seen than any only six sigma project or only lean project. While Lean focuses on eliminating non-value added steps and activities in a process, Six Sigma focuses on reducing variation from the remaining value-added steps.

In this project, for lean thinking; non-value added effects are defined and also eliminated; KANBAN is used in assembly line. Analysis of Customer Value Add time leads to identification of efficiency issues within the process. Thus, Lean techniques tend to speed up processes by making them more efficient. Already the mainly aim which is defined “to decrease delivery time” means that a simplification, type of getting lean.

In the way of six sigma, standardization of non-standard orders are done, adapting non-standard procedures into standard are applied such as SOC, BOM, inputs materials, so on. Thus, Six Sigma techniques provide to decrease variation of delivery time and also eliminate out-of-control points in the delivery process.

All in all, it is achieved after this project that the reduction of waste and variation, saving time and money. It means that shorter delivery time, customer satisfaction, keeping continuous improvement to improve business processes and products, business philosophy & strategy that are recognized by leaders in world class and more competitive company in the market globally.

The opportunities of this project can be enlarged as follows;

- Less variation provides more accurate process
- Materials, labor, resource capacity, process documentations are designed to gaining maximum profit and to satisfy customers.
- Reducing the Non Value Added activities, adding more value to process
- Continuous improvement for delivery process of the mentioned product
- Because of the achievement, it gives encourage to carry out this quality to other products.
- Create an opportunity to apply lean six sigma methodology to other products tree.

REFERENCES

- [1] Jugulum R.; Samuel P.: “Design for Lean Six Sigma, A Holistic Approach to Design and Innovation”, John Wiley & Sons, Inc., Hoboken, New Jersey, USA **(2008)** 41-55.
- [2] Six Sigma Training Assistant: Six Sigma – DMAIC vs. DMADV in the Field of Customer Service, **(6-10-2009)** <http://www.sixsigmaonline.org/six-sigma-training-certification-information/articles/six-sigma—dmaic-vs-dmadv-in-the-field-of-customer-service.html>
- [3] Mefford R.N.: “Increasing productivity in global firms: The CEO challenge”, *Journal of International Management* 15 **(2009)** 262-272.
- [4] Andersson S., Armstrong A., Björe A., Bowker S., Chapman S., Davies R. :” Making medicinal chemistry more effective—application of Lean Sigma to improve processes, speed and quality”, *Drug Discovery Today*, Volume 14, **(June 2009)**
- [5] Melton T.: “The Benefits of Lean Manufacturing”, Institution of Chemical Engineers, 7. *World Congress of Chemical Engineers*, 83 **(2005)** 662–673.
- [6] Schroeder R.G., Linderman K., Liedtke C., Choo A.S.: “Six Sigma: Definition and underlying theory”, *Journal of Operations Management* 26 **(2008)** 536–554.
- [7] Markarian J.: “What is six sigma”, *REINFORCED plastics*, Volume 48, Issue 7, **(July/August 2004)** 46-49.
- [8] Taghizadegan S.: “Essentials of Lean Six Sigma“, Elsevier Inc., Academic Press, USA **(2006)** 2-160.
- [9] George M.; Rowlands D. and Kastle B.: “What is Lean Six Sigma?”, McGraw Hill, USA **(2004)** 2-94.
- [10] George M.L.: ”Lean Six Sigma, Combining Six Sigma Quality with Lean Production Speed”, McGraw Hill, USA **(2002)** 29.

- [11] Dirağ, A., “Failure Mode and Effect Analysis (FMEA) and An Implementatiin Study in A Packaging Company”, M.Ü.FBE, YL. Tezi, 2008
- [12] “Using FMEA for Defining Lean Six Sigma for Service Solutions”, *Six Sigma Service*, (2009) <http://lssacademy.com/2007/06/28/10-steps-to-creating-a-fmea/>
- [13] Pereira R., “10 Steps to Creating a FMEA”, *Lean Six Sigma Academy*, (2007) <http://www.sixsigma4service.com/definition-using-fmea-lean-six-sigma-solution.html>
- [14] “Failure Modes and Effects Analysis Guide”, Manufacturing Technology Committee – Risk Management Working Group, Risk Management Training Guides, (2008)
- [15] Sheridan, J.: “Aircraft-Controls Firm Combines Strategies to Improve Speed, Flexibility and Quality.” Gale Group, Penton Media, Inc. (2000).
- [16] Dubai Quality Group “The Birth of Lean Sigma”, The Manage Mentor, Dubai (2003).
- [17] Smith, B. and Adams, A.: “Lean Sigma: Advanced Quality.” ASQ’s 55th Annual Quality Congress Proceedings (2001) 55.
- [18] Smith, B.: “Lean and Six Sigma A One-Two Punch.” Quality Progress (April 2003)
- [19] Goyal, N.: “Applying Lean Manufacturing to Six Sigma – A Case Study.” ISixSigma, website, Six Sigma Article Spotlights (2002). www.isixsigma.com
- [20] McIlroy, J. and Silverstein, D. “Six Sigma Deployment in One Aerospace Company.” Six Sigma Forum website (2002). www.sixsigmaforum.com
- [21] Kandebo, S.: “Lean, Six Sigma Yield Dividends for C-130J” Aviation Week & Space Technology, New York, (July 12, 1999).

- [22] Illing, J.:“Seamless Integration of Lean Enterprises and Six Sigma.” Automotive Manufacturing and Production 113 (2), 66 (2001).
- [23] Rucker, R.:“Citibank Increases Customer Loyalty With Defect-free Processes.” The Journal for Quality and Participation Cincinnati, (Fall 2000).
- [24] Trombly, R. “Running lean running strong: lean manufacturing processes lead to a stronger, more efficient business.” Reed Business Information, Gale Group (2002).
- [25] Sharma, A. and Moody, P. “The Perfect Engine.” The Free Press, (2001).
- [26] Drickhamer, D.: “Best Practices – Where Lean Meets Six Sigma.” Industry Week (2002).
- [27] Mills, C., Wheat, B., and Carnell, M.:“Leaning into Six Sigma.” Publishing Partners (2001).
- [28] Smith, B. :“Integrating Six Sigma and Lean Manufacturing.” Six Sigma Forum website (2002). www.sixsigmaforum.com
- [29] Keller, P.: “Recent Trends in Six Sigma.” ASQ’s 55th Annual Quality Congress Proceedings (2001).
- [30] Kandebo, S., “Lean, Six Sigma Yield Dividends for C-130J”, Aviation Week & Space Technology, Vol. 10, 75-83, (1999).
- [31] Sheridan, J., “Aircraft-controls Firm Combines Strategies to Improve Speed”, Flexibility and Quality, Vol. 22, 120-125, (2000).
- [32] Bossert, J., Walker, R., “Total Quality Management and Performance, an Evaluation of the Evidence and Lessons for Research on Public Organizations”, Public Performance & Management Review Journal, Vol. 26, 111-131, (2002).
- [33] Dubai Quality Group, “The Birth of Lean Sigma”, The Manage Mentor, Dubai, 11-38, (2003).

- [34] Pojasek, R. B., “Lean, Six Sigma and the Systems Approach: Management Initiatives for Process Improvement”, *Environmental Quality Management*, 85-92, **(2003)**.
- [35] Brett, C., Queen, P., “Streamlining Enterprise Records Managements with Lean Six Sigma”, *The Information Management Journal*, 58-62, **(2005)**.
- [36] Furterer, S., Elshennawy, A., “Implementation of TQM and Lean Six Sigma Tools in Local Government: a Framework and a Case Study”, *Total Quality Management*, Vol. 16, 1179- 1191, **(2005)**.
- [37] Marti, F., “Lean Six Sigma Method in Phase 1 Clinical Trials: A Practice Example”, *Quality Assurance Journal*, Vol. 9, 35-39, **(2005)**.
- [38] Bendell, T., “Structuring Business Process Improvement Methodologies”, *Total Quality Management*, Vol. 16, No 8-9, 969-978, **(2005)**.
- [39] Kumar, M., Antony, J., Singh, R.K., Tiwari, M.K., Perry, D., “Implementing the Lean Sigma framework in an Indian SME: a case study”, *Production Planning and Control*, 407-423, **(2006)**.
- [40] D’Angelo, R., Zarbo, R.J., “The Henry Ford Production System: Measures of process defects and waste in surgical pathology as a basis for quality improvement initiatives”, *American Journal of Clinical Pathology*, Vol. 3, 423-429, **(2007)**.
- [41] Antony, J., Kumar, M., Labib, A., “Gearing Six Sigma into UK Manufacturing SME’s: Results From A Pilot Study”, *Journal of The Operational Research Society*, Vol. 4, 482-493, **(2008)**.
- [41] Schneider Electric Company, Company profile, History, Strategy, <http://www2.schneider-electric.com/sites/corporate/en/group/company-profile.page>, **(2011)**

RESUME

Name-Surname : Canan YILDIRIM

Birth of Date&Place: 25.08.1986/ Sarıyer

Education

High School : Kağıthane Anatolian High School, İstanbul, 2004

Undergraduate : Marmara University, Chemical Engineering, 2008

Graduate : Marmara University, Industrial Engineering, 2008-...

Address : Kavacık Kaptanlar Cad. Savcı Sok. No:12 D:11
Beykoz / İstanbul

Telephone : 555 5591117

E-mail : cananyldrm1986@gmail.com