

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF
SCIENCE ENGINEERING AND TECHNOLOGY

**A PROCESS IMPROVEMENT OF FACILITY TEST EFFICIENCY WITH SIX
SIGMA METHODOLOGY IN AUTOMOTIVE INDUSTRY**



M.Sc. THESIS

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Department of Management Engineering

Management Engineering Programme

Thesis Advisor: Prof. Dr. Hatice CAMGÖZ AKDAĞ

July 2020

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To my dear mom, dad & spouse,



FOREWORD

First of all, I would like to start by thanking dear thesis advisor, Prof.Dr.Hatice CAMGÖZ AKDAĞ for her fully support.

Then I would like to give special thanks to my managers who helped me meet Six Sigma and discover its world.

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And my dear spouse-Cihad KASNAK, thanks to you I succeed.

June 2020

Aslı BEŞİR KASNAK
Senior Project Engineer



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A PROCESS IMPROVEMENT OF FACILITY TEST EFFICIENCY WITH SIX SIGMA METHODOLOGY IN AUTOMOTIVE INDUSTRY

SUMMARY

This paper presents a work on a Six Sigma implementation as a process improvement on facility test efficiency in an automotive sector. Aim of this work, eliminate waste times and create test efficiency with Six Sigma on a case study. Case study covers the automotive tests and defect analysis applies on these (randomly selected) tests. In the first step, randomly selected automotive tests were measured. And secondly, non-value activities and waste times were determined. After that, defects were identified, and potential solutions were applied with six sigma methodologies via DMAIC (Define-Measure-Analyze-Improve-Control) and root cause techniques (Fishbone diagrams, flow chart analysis, pareto analysis, SIPOC matrices). The implementation of potential solutions had resulted as with aimed improvement.

Facility Test Efficiency Improvement case study arise from high rates of variations on durations of automotive tests. Users of this system (internal and external all customers) says that durations and its variation shall be decreased. These durations and variations cause the cost of poor quality as higher testing costs and wasting times, lower efficiency. Therefore, problem statement, scope and goal are determined as facility tests duration shall be decreased by optimizing change on processes with Six Sigma methodology. In this case study, firstly define wastes and variations as measurements. Therefore, 22 tests are chosen and measured. Historic data also shows similar results. Data divided into two groups for better analysis. 1st phase covers the preparing test steps, 2nd phase covers the test steps.

Voice of the customer: Test durations (1st phase and 2nd phase) takes too much time. The duration variates depending on the issues arisen. This duration and its variation shall be decreased.

CTQ Statement (Critical to Quality): Testing shall be no more than 100mins for all test processes.

Defect Definition for Y (Objective Metric): 1st phase and 2nd phase of tests durations

Cost of Poor Quality: Poor process quality causes higher testing cost. Due to longer test durations. Unable to fully support programs with efficiency.

Problem Statement, Scope, And Goal: Tests duration shall be decreased by optimizing change on 1st phase and 2nd phase.

In summary, with our six-sigma process improvement project, test times have been reduced from 479 minutes to 180 minutes. This indicates an improvement of approximately 82%. With this result, the test times have been shortened, thus there has

been no cost decrease in hourly prices paid to the test center. At the same time, engineering hours were reduced, and more efficient hours were obtained. Thanks to the planned clocks, productivity has been significantly increased for both the firm and the test center, and the loss of motivation due to the complexity of the process has also been prevented. The project was closed with an achievement above the optimal level in terms of time, cost and motivation, and the same processes are continuing with the established processes.



OTOMOTİV ENDÜSTRİSİNDE ALTI SİGMA METODOLOJİSİ İLE TEST MERKEZİ TEST VERİMLİLİĞİNİN SÜREÇ İYİLEŞTİRMESİ

ÖZET

“Otomotiv Endüstrisinde Altı Sigma Metodolojisi İle Test Merkezi Test Verimliliğinin Süreç İyileştirilmesi” tezi bir süreç iyileştirme projesidir. Türkiye’nin lider otomotiv firmalarından birinde örnek olay üzerinden gerçek veriler üzerinden gerçekleştirilmiştir. Bu çalışmanın verileri araç testlerinin yapıldığı ve ilgili firma lokasyonundan ve kendilerinden bağımsız bir firmada ve saatlik ücret ödenerek yapılan test merkezinde toplanmıştır. Bu çalışmanın çıkış noktası otomotiv firmasının son zamanlarda artan test maliyetleri, verimsiz mühendislik saatleri ve edinilen başarısız test sayılarının artması olmuştur. Test süreçlerinde gerçekleşen bu verimsizlik dikkat çekici bir düzeye ulaştığı için süreci anlama ve iyileştirme çalışması başlatılmıştır. Süreç iyileştirme projesinde sürecin net şekilde analiz edilebilmesi ve somut şekilde aksiyonlar alınıp sürecin iyileştirilmesi hedeflenmektedir. Altı sigma metodolojisi projenin en başında, projenin beklentilerine en uygun çıktıları matematiksel ve istatistiksel metodlarla verebileceği saptandığı için seçilmiştir. Yapılan iyileştirmenin maliyet anlamında ciddi çıktılar sunması beklenildiği için sezgisel değil matematiksel yöntemlerle ilerlenmesi kararlaştırılmıştır. Altı sigma metodolojisi geniş seçenekler sunmaktadır ancak süreç yönetimi ve veri setlerinin özelliklerine uygun olarak DMAIC metodolojisi yol haritası olarak seçilmiştir.

Proje başlangıcında ilk durumunun net şekilde anlaşılması için ön çalışmalar yapılmıştır. Öncelikle ele alınan sürecin bir haritası çıkarılmıştır, bununla paralel olarak proje ve süreç paydaşlarının yani iç ve dış müşterilerin beklentilerini anlamak üzere de veri toplama aksiyonları alınmıştır. Bu noktada projenin başlangıç safhasında müşteri beklentileri analiz edilerek, ana süreç resmedilmiştir. Müşteri beklentisi çok fazla süren test sürelerinin kısaltılmasıydı. Her testin farklı sürelerle sahip olabildiğini, standart bir süre olmadığını yani vasyasyonun çok yüksek olduğunu belirtmiştir. Süreç haritalanırken de daha spesifik çalışabilmek adına süreç 3 ana bölüme ayrılmıştır : Teste hazırlık sürecini kapsayan 1.adım, test alanına varıştan testin başlangıç süresine kadar olan süreyi ifade eden 2.adım ve son olarak testin gerçekleşmesi ve sonuçlanmasıyla tamamlanan 3. adım tanımlanmıştır. 3.adım bilgisayar ve tanımlı test prosedürleri üzerinden işlediğinden dolayı hataya ve müdahaleye açık olmadığı için bu süreç projenin hedef kapsamı içine dahil edilmemiştir. Bu aşamadan sonra yapılan balık kılçığı diyagramı ile kök neden analizi yapılırken beş ana etmen olan yönetim, metodlar, malzemeler, insanlar ve sistem üzerinden problemler tanımlanmıştır. Balık kılçığı ile de sürecin 1. Ve 2. Adımları sayılan 5 ana etmen ile varyasyona

uğramaktadır. Tüm bu bilgilerin ışığında, proje kapsamı test süreçlerinin 1. ve 2. adımlarında saptanacak aksiyonlarla iyileştirmeyi sağlamak olarak belirlenmiştir. Mevcut durum ölçümleri, bir test süresinin (1. ve 2. Adımların toplamı) ortalama olarak 7 saati geçen zaman dilimlerine tekabül ettiğini, ancak olması gerekenin ise 2-3 saat (1. ve 2. Adımların toplamı) olduğu belirlenmiştir.

Pareto analizi yapabilmek için süreç adımları Y1 (1.adım fonksiyonu) ve Y2 (2.adım fonksiyonu) olmak üzere gruplanmıştır. 1. adım fonksiyonu için süreç adımları olan haftalık test planlaması (X1.1) ve planlama toplantılarının düzeni (X1.2) tanımlanmıştır. 2. Adım fonksiyonu için ise 11 farklı adım tanımlanmıştır. Test alanı girişi (X2.1), giriş kartının alınması (X2.2), test alanına varış (X2.3), teknisyenlerin aranması (X2.4), test aracının test alanına girmesi (X2.5), test aracının test alanı ile bağlantısının sağlanması (X2.6), araca bilgisayar ile bağlanması (X2.7), enstrümantasyon modüllerinin bağlanması (X2.8), test kalibrasyonun yapılması (X2.9), test kontrol odası ile testin başlayabilmesi için görüşülmesi, onay alınması (X2.10) ve testin başlaması (X2.11) adımları fonksiyona uygun şekilde tanımlanmıştır. Pareto analizinde bu adımlar ve sürelerinin varyasyon frekansları çalışılmıştır. Pareto'nun 80/20 kuralına uygun olarak hedefimize en hızlı ve doğru şekilde ulaşabilmek için hedef önceliklendirmesi yaptık. Bu analizde Y1 fonksiyonunun 2 alt adımı yüksek orana sahip olmuştur. Y2 fonksiyonuna ait aksiyonları da sıralayabilmek adına yalnızca onun alt adımlarını içeren bir Pareto analizi daha çalışılmıştır ve bu analiz sonucunda da hedef aksiyonlar belirlenmiştir. Pareto analizi sonucu olarak hedef alt süreçler en etkilisinden en az etkilisine doğru X1.1, X1.2, X2.11, X2.9, X2.2, X2.5, X2.6, X2.10, X2.7, X2.4, X2.8, X2.1 ve X2.3 şeklinde sıralanmıştır.

Analizlerin ardından toplanan geçmiş veri seti ve örnek veri setleri her 2 adım için de biraraya getirilmiştir. Hedefler net olarak tablolaştırılıp, toplanan veri setlerinin istatistiksel kontrollerine geçilmiştir. Projenin bundan sonraki aşamalarında MINITAB istatistiksel analiz programı kullanılmıştır. MINITAB'deki ilk aşamada toplanan verilerin tamamı sisteme giriş yapılmıştır. Hesaplamaların sağlıklı ilerleyebilmesi için tüm veriler için normallik testleri sistem üzerinde yapılmıştır. Normallik testi, elimizde veri setinin ortalama değer (mean), standard sapma ve ölçüm sayısına uygun olarak normal dağılıma sahip olup olmadığının kontrolüdür. Normallik testi için birden fazla test tipi bulunmaktadır. MINITAB üzerinde önerilen ve en başarılı, kesin sonuçlar veren Anderson-Darling testi (AD testi) kullanılmıştır. Normallik testine göre topladığımız ilk durum verileri de örnek durum verilerinin de normal olduğunu raporların "P değeri"nin 0.05'den büyük olması durumuyla edinmiş olduk. Verilerimiz normal ve diğer hesaplamalar için uygundur sonucunu çıkartabildik. Normallik testlerinden sonra ilk durum verilerinin ve örnek olay verilerinin birbirinden farklı olmadığının da kontrolünü "Eşit varyanslar testi" ni MINITAB üzerinden yaparak test ettik. Hem 1. adım hem de 2. adım için ilk durum verileri ve örnek olay verileri karşılaştırılmış olup, her biri için testlerin benzer varyanslara ait olduğu ortaya çıkmıştır. Karşılaştırılan verilerin birbirleri ile örtüşmemesi durumunda bu testin negatif olduğu yorumlanacaktı ancak bizim testlerimiz pozitif olarak sonuç vermiştir.

İstatistiksel kontrol süreçlerin verilerin normalliği ve birbiri ile örtüşür durumda olması durumlarından sonra ise süreç yeterlilik testleri gerçekleştirilmiştir. Süreç yeterlilik testleri Cpk sonucu çıkartan ve alınan verilerin alt ve üst limitler de belirlenerek genel konumu hakkında bilgi vermektedir. Bu testin ana ölçütü Cpk'dir. Eğer Cpk sıfırdan küçük ise sürecin yeterli olmadığı şeklinde yorumlanır. Eğer Cpk değeri sıfırdan büyük ise sürecin yeterli ve verilerin varyasyonunun az olduğu şeklinde yorum yapılabilir.

Testlerimizin 1. ve 2. adımları için süreç yeterlilik testleri de MINITAB uygulaması üzerinden gerçekleştirilmiştir. Her iki adım için de gerçekleştirilen süreç yeterlilik testlerinde Cpk değeri sıfırdan küçük olarak çıkmıştır. 1. Adım süreç yeterlilik testi sonucu -0.841 olarak, 2. Adım süreç yeterlilik testi ise -0.68 olarak çıkmıştır. Bu da süreçlerimizin yeterli olmadığını bize kanıtlamaktadır.

1.adım ve 2. adım veri ölçümlerinden sonra ideal süreç haritalaması yapılmıştır.Bu süreç haritalamasında gelişim aksiyonları ile elimine edilmiş adımlar ile oluşturulmuştur. Bu süreç haritasında da ilk başta yapıldığı gibi test süreçleri üç ana adıma ayrılmıştır. Aksiyon tablosu ise optimizasyon ve gelişim aksiyon tipleri olmak üzere kategorilere ayrılmış ve 12 farklı aksiyon belirlenmiştir. Bu aksiyonlar şirket bilgi gizliliği sebebiyle açıklanamamaktadır. Fakat bu 12 aksiyonun 4 tanesi optimizasyon, geri kalan 8 tanesi ise gelişim aksiyon kategorisindedir. Bu gelişim adımlarından sonra ideal süreç haritasından da başarıyla altı sigma süreçlerinin tamamlandığı görülmektedir.

Sonuçlardan emin olabilmek için, altı sigma DMAIC metodolojisinin son adımı olan kontrol adımında da örnek ölçümler gerçekleştirilmiştir. Tezde önce ve sonrası analiz olarak yer verilen kontrol aşamasında da 1. adım ve 2. adım olarak analizler iki yapıya ayrılmıştır. Öncesi ve gelişim aksiyonları sonrası değişimi somutlandırmak için olasılıksal grafikler çalışılmıştır. Olasılık grafiklerinde önceki ve sonraki verilerin aralık olarak dağılımları, standart sapma ve ortalama(mean) değerlerine göre verilmiştir. Bu dağılım tablolarında gelişim öncesi verilerin çok daha uzun test sürelerini gösterirken, geniş varyasyon aralığında dağıldığını göstermektedir. Ancak gelişim sonrasında ise dağılım çok daha dar bir aralıkta ve benzer sonuçlarla karşımıza çıkmaktadır. İlk aşamada yaptığımız gibi “Eşit varyanslar testi” bu noktada da gerçekleştirilmiş olup, bu kez gelişimden sonra artık eski süreç verileri ile herhangi bir örtüşme olmadığı açıkça görülmüştür. Bu da süreçlerin zaman bakımından geçmiş ile kesişmeyecek kadar daraltıldığını ifade etmektedir.Kutu grafiğinde ise yine önce ve sonra verileri karşılaştırılarak ortalama değerler ve değer değişimleri kümeleri karşılaştırılmış olup aradaki kesişim olmayan tablo kanıtlanmıştır.

Bir önceki bölümde 1. Ve 2. adım için ayrı ayrı yapılan bu testlerden sonra toplam süreç verisi ile süreç yeterlilik testleri gerçekleştirilmiştir. Son süreç yeterlilik testinde Cpk değerimiz 1.25 olarak edinilmiştir. Cpk değerinin sıfırdan büyük olması sürecin yeterli, sıfırdan küçük olması ise yetersiz olduğu anlamına gelmekteydi. Gelişim aksiyonlarından önce Cpk değerlerimizin hepsi sıfırdan küçük olarak alınmasına rağmen, altı sigma ile iyileştirdiğimiz bu proje ile süreçlerimizin yeterli hale geldiğini istatistiksel olarak da edinmiş olduk.

Özetle, altı sigma süreç iyileştirme projemizle test süreleri 479 dakikalardan 180 dakikalara indirilmiştir. Bu da yaklaşık %82’lik bir iyileşmeye işaret etmektedir. Elde edilen bu sonuç ile test süreleri kısalmış böylece test merkezine ödenen saatlik bedellerde bir maliyet düşüşü yaşanmıştır. Aynı zamanda mühendislik saati de azaltılarak daha verimli saatler edinilmiştir. Planlı saatler sayesinde hem firma hem de test merkezi için verimlilik ciddi ölçüde arttırılmış olup, sürecin karmaşasından kaynaklı motivasyon kayıpları da önlenmiştir. Zaman, maliyet ve motivasyon açısından optimal seviyenin üzerinde bir başarı ile proje kapatılmış, şu anda da oturtulmuş süreçlerle aynı işlemler sürmektedir.



1. INTRODUCTION

This paper presents a work on a Six Sigma implementation as a process improvement on facility test efficiency in an automotive sector. Aim of this work, eliminate waste times and create test efficiency with Six Sigma on a case study. Case study covers the automotive tests and defect analysis applies on these (randomly selected) tests. In the first step, randomly selected automotive tests were measured. And secondly, non-value activities and waste times were determined. After that, defects were identified, and potential solutions were applied with six sigma methodologies via DMAIC (Define-Measure-Analyze-Improve-Control) and root cause techniques (Fishbone diagrams, flow chart analysis, pareto analysis, SIPOC matrices). The implementation of potential solutions had resulted as with aimed improvement.

Facility Test Efficiency Improvement case study arise from high rates of variations on durations of automotive tests. Users of this system (internal and external all customers) says that durations and its variation shall be decreased. These durations and variations cause the cost of poor quality as higher testing costs and wasting times, lower efficiency. Therefore, problem statement, scope and goal are determined as facility tests duration shall be decreased by optimizing change on processes with Six Sigma-DMAIC methodology.

This paper has 4 main sections are: Literature review, Methodology, Analysis and Results, and Conclusion. First chapter is literature review has the Six Sigma and used industries, six sigma and automotive industry and case studies sub-parts.

Second chapter is methodology has the below titles are the following:

- Sigma & Six Sigma Definition
- Six Sigma Methodology
- Voice of the Customer
- CTQ Statement (Critical to Quality)
- Cost of Poor Quality (COPQ)
- SIPOC Matrix and SIPOC Diagram
- Key Process Output Variable (KPOV) Metrics
- Process Mapping
- Fishbone Diagram

- Data Collection Plan
- Pareto Analysis
- MINITAB
- Statistical Quality Control - Control Charts, Normality Tests, Test for Homogeneity of Variances, Process Capability

Third chapter of this paper is “Analysis and Results” have application of the case study, MINITAB tables and histograms, and results of the Six Sigma case study with proven datasets.

Last chapter of thesis is given a summary about thesis’ route and results.



2. METHODOLOGY

2.1 Six Sigma and Industrial Perspective

The term Six Sigma was introduced as a business process management in the mid-1980s by Bill Smith, an engineer at Motorola in response to the growing competitiveness of products from Japan [1]. At that time, Japanese companies in electronic industry offered a lower price and higher quality, so American companies needed to improve their products to successfully compete in global and domestic markets [2]. Many organizations launched Six Sigma initiatives from that moment achieving greater success, but it is especially noteworthy the case of General Electric (GE) [3]. GE played a very significant role in the development of Six Sigma as a methodology because they decided to add a 'define' step at the beginning of the MAIC process (*measure, analysis, improve and control*) to clarify the problem addressed [4].

Six Sigma is normally applied in large firms. For example, GE made an investment as \$350 million for six sigma and get \$1 billion. According to number of industry advisors, because smaller firms do not benefit from the resources owned by large firms, the implementation of Six Sigma in small firms needs a different structure, in comparison with large firms [5].

Six Sigma have been adopted by different industry and service [6]. They have been used to effectively improve companies' performance [6]. However, in the food industry their adoption is still very low and developing countries [6].

Six Sigma is a problem-solving method that can be used in any business automotive, food, aerospace etc. Main idea of the six sigma is reduction variations and defects on selected/needed products and services in any business [7].

Food Industry and Six Sigma: The food industry have a great variety of products. Food industry products have short delivery times (because of expire dates, proper storage and transportation conditions). Assurance, safety, health, and hygiene of the food products effects food products' quality and prices. At this point, Six Sigma is used for food industry's variations and wastes. The food industry applied large number of different tools to implement Six Sigma, mainly to reduce process variation and cost, to increase productivity and competitiveness [8]. These initiatives face some barriers to implementation, including human factor and food industry characteristics [8].

Medical Industry and Six Sigma: The medical industry is other named healthcare industry have constantly growing. Hospitals, care facilities are main facilities of medical industry and most important aim is improving patient care. With the Six Sigma in the medical industry, healthcare organizations can focus on reducing wastes, cost, and improving customer (patient) satisfaction [9]. The McKinsey Global Institute (2012) found that inefficient and unnecessary health administration practices increased spending and caused \$91 billion in wasteful costs which accounted for 14% of the total spending. Therefore, Six Sigma become significantly important.

Aerospace-industry and Six Sigma: Six sigma processes can be followed through best practices. Following example shows how engineers newly trained on Six Sigma can create changes. A manufacturer in aerospace industry wanted to reduce the manufacturing costs and decided to implement six sigma procedures. They aimed to reduce cost through slashing the machining cycling time by half.

After six sigma certification they built a team with key engineers, managers and machine operators. They first define the cycle time, measured at 1200 seconds. Then listed the risk factors; overtime reduction, less time for inspection. Measuring phase revealed possible improvement areas. In the improvement phase, potential solution listed and presented, ranked. With the approved and reliable process, process steps decreased by 20%. After the implementation at Six Sigma procedures and principles, 46% cut in the cycle time was achieved.

General Electric, Motorola and any same manufacturing business area used Six Sigma firstly. Therefore, Six Sigma firstly spread with manufacturing industry. But Six Sigma is related the quality issues, after this is understood, Six Sigma spread to other industries.

In today's world, every industry and business desires to achieve excellence and management is committed to produce and deliver flawless products, solutions or services, to promote first time right production and the zero defects concept, training people and motivating staff, keeping environmental protection integrated in all activities and involving staff members towards the excellence of an organization [10]. Literature shows that Six Sigma is used in mostly manufacturing industry, plastics industry, automotive industry and electrical industry. Figure 2.1 shows other industries which are medical and healthcare industry, pharmaceutical industry, enterprise, plants, rolling mill, material handling and color industry.

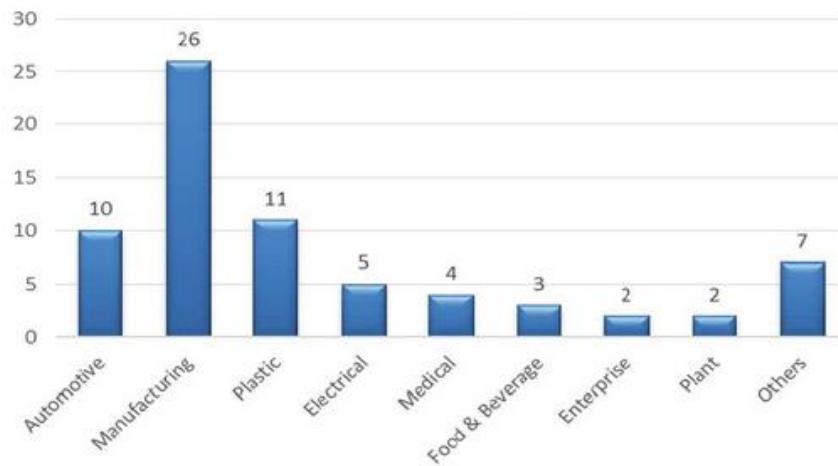


Figure 2.1: Number of research articles industry-wise.

Source : Amitkumar Dhanjibhai Makwana & Gajanan Shankarrao Patange (2019) A methodical literature review on application of Lean & Six Sigma in various industries, Australian Journal of Mechanical Engineering, DOI: [10.1080/14484846.2019.1585225](https://doi.org/10.1080/14484846.2019.1585225)

2.2 Six Sigma and Automotive Industry

Automotive industry is the most important industry for the Six Sigma. Because automotive industry has very active improvements. Therefore, must adopt quickly related high the quality improvement, lower production cost and continuous improvement activities. Manufacturing industry and automotive industry has many case studies related Six Sigma (Figure 2.1). According to the researches, Six Sigma is more popular in automotive firms like General Motors Company (GM), Toyota, Ford Motor Company, Tenneco and many more.

There are some examples of automotive industry six sigma cases as following:

GM Case: General Motors Company (GM), is an American multinational corporation headquartered in Detroit that designs, manufactures, markets, and distributes vehicles and vehicle parts, and sells financial services, with global headquarters in Detroit's Renaissance Center. General Motors (GM) is a company founded in the USA in 1908. The company is the largest American automobile manufacturer, and one of the world's largest. General Motors automobile brands are Chevrolet, Buick, GMC, and Cadillac. Additionally, GM have ownerships of foreign brands such as Holden, Wuling, Baojun, and Jiefang. GM is the world leader in vehicle safety and innovation with alternative energy engine technologies. In 2015, GM had a problem related Cadillac Escalade SUV 22-inch chrome wheels because of GM's supplier had inadequate production

numbers [11]. Therefore, GM decided to use six sigma methodology to solve this problem. GM' vice president aimed to get \$3 billion, 10% increased profit margins, and 10% increased customer loyalty points by the eliminating wastes. First step of the Cadillac Escalade SUV 22inch chrome wheels problem solution focused capacity changing with re-design and re-engineering work of wheel. In the parallel of this activity, logistics activities observed and determined wastes. First saving money came from logistics steps. New logistics steps have less four steps and has new route. At the end of the six sigma processes, GM decided to transfer wheels production to Arlington Assembly Plant in Texas. Additionally, because of researching and engineering, GM realized that one difference is only one attachment is not needed so decided to use old version of the wheels. Second saving item came from this step \$5 billion as scrap cost saving. GM reduces price of custom wheels to \$ 1,000. Thus, GM saved more than \$ 15 million at the start of the project. Now, GM looks again with this side to all processes. Another Six Sigma saving in GM as these: \$ 30 million cost savings from scrap reduction. GM is used Six Sigma for sales, human resources, product development, logistics and supplier quality departments.

Toyota Case: Toyota (Toyota Motor Corporation) is a Japanese multinational automotive manufacturer. Toyota is the largest automobile manufacturer in Japan. In the world, the second-largest automotive manufacturer is behind Volkswagen. Toyota is the global market leader of hybrid electric vehicles sales. Toyota Motor Corporation was founded by Kiichiro Toyoda in 1937, as a spinoff from his father's company Toyota Industries, to create automobiles. Toyota manufacture vehicles with five brands as Toyota, Hino, Lexus, Ranz, and Daihatsu.

Toyota Production System (TPS) can be defined as supercharged lean six sigma program. Toyota created TPS in-order-to achieve the best quality, low price and shortest lead time through minimizing wastes. TPS continuously improved by growing quality and consistency of the work [12].

Eliminating the waste is one of the core pillars of TPS. TPS cost importance to detection and elimination of waste by six sigma tools. TPS's the most important six sigma strategies can be listed in four categories. These four categories can be read as what Toyota focuses most [12].

- Setup decreasing times: It takes time, to make setups; labor time equipment time. By changing all the procedures for setup, Toyota decreased setup times from month to hours [12].
- Producing more with less: Producing in big quantities is not always profitable. It demands huge setups, high capital, large inventories and longer lead times which are all costly. With TPS, Toyota find the ideal method for reducing with an inexpensive and short setup so that it become possible to produce various thing in small amounts [12].
- Inclusion of workers for producing more with less: Toyota created smaller management groups of employees. They are trained to carry out their specialized tasks. While also learned how to repair their own work of equipment [12].
- Dealers are company partners: Toyota's dealers are like company partners. Dealers are being thought with the ways of decreasing setup times, defects, inventories and sustain their own work of equipment. Most special about TPS is that it combines attitude, Notion and unique techniques into their whole work environment and system so that six sigma procedures become a standard in Japan them spread to west. Many terms we use today are mainly strategies derived from Toyota's six sigma system; Just in time, stockless production, world class manufacturing [12].

Ford Motor Company: Ford Motor Company is one of the largest and the oldest motor company in the USA with 70 factories all over the world. At the edge of 2011 Fiesta launch, cosmetic defect in the vehicle's carpet cost a threat to the launch of 2011 Fiesta [13]. Body interior design team created six sigma procedures for quality improvement of the carpet. Body interior six sigma team approached to the supplier and analyzed the manufacturing processes and find out the problem was related to the settings of the machine called needler. However, changing the settings in the needler could affect other critical qualities like durability, stain resistance and plushness. In-order-to complete the task, experts used "Design of Experiment (DOE)" tool. The team designed the tool with only 34 runs to understand what they need. Result of the runs in the tool showed that needler setting that eliminated the brush mark problems did not affected the plushness. After the optimal settings has been done and new carpet has been evaluated well, samples sent to Ford's Research and Engineering Center for final control. The key result in this case is, from the definition of the problem to pass all

quality tests, it took only 12 days [13]. By this fast result, Ford could make the successfully launch of the 2011 Fiesta [13].

By the time Ford decided to implement six sigma methodologies in the late nineteens. It became the first company that to do that at a large scale in Automotive industry.

Their goal was to reduce costs, improve their products' quality, increase the consumer satisfaction rates, and reduce their environmental impact (so that reducing the cost again) [14]. In the case of improving quality, difference of 99% and 99,9996% quality level in a million products is 10.000 defects to 4 defects. By implying Six Sigma, Ford could make this giant leap. Ford achieved this goal to reduce defect rate to just one defect for every 14,8 vehicles [14]. Ford's consumer driven six sigma initiative, they eliminate more than 12 billion in the last two decades worldwide with more than 10000 projects improved by the completion of six sigma strategies [14].

Tenneco: Tenneco is a company which produces clean air and ride performance products for cars, trucks and vehicles. It operates in the engineering centers and 90 factories worldwide and manufactures products for more than 100 countries.

Tenneco follows six sigma procedures and lean production systems to sustain their quality levels and have the high efficiency in all their plants [15].

In a Tenneco plant which produces steel tubing of exhaust system, a goal of reducing scrap rate in the production of 2.5-inch tubes by 50% was set [15]. Six sigma team of Tenneco first established the 5 steps approaches; define, measure, analyze, improve, control. Process showed the areas of possible improvements, tool wear, alignment weld zone temperature, pressure and inspection and data collected in these improvement areas. After variance analysis of the data collected, the team concluded that improvements in the tooling and well zone temperatures will be the focus of the efforts. And final-result showed that goal of reducing the scrap by 50% was achieved [15]. This Six Sigma improvement did not affect just 2.5-inch tubes but all the manufacturing procedures of steel tubing in different size in all Tenneco facilities [15].

3. LITERATURE REVIEW

Methodology part include a detailed explanation of the tools and methods used in the thesis. It is aimed to create preliminary information for all methods used in the thesis with this section. The methodology part proceeds according to the method order used in the application section.

The content of this section is as follows. Firstly, this part starts with the definition of sigma and Six Sigma, where the starting point, goal. Then comes the definition of six sigma as mathematical and statistical sides. Mathematical function transformation is given in this part. Secondly, six sigma methodology is described with own tools and own methods. DMAIC (define, measure, analyze, improve and control) and all phases, tools are summarized on the last part of six sigma methodology.

Voice of customer (VOC) definition and methods are summarized in third section of methodology. After the third section, CTQ Statement (Critical to Quality) is described with VOC relationships. Fourthly, subtitle of the “Cost of Quality” is Cost of Poor Quality (COPQ) is located on this section. In the SIPOC Matrix and SIPOC Diagram part have its definition and a quick summary of data set relationships thus far. Key Process Output Variable (KPOV) Metrics comes the part about what we call metrics related key outputs. Process Mapping is the subtitle of “Business Process Management (BPM)”. In the process mapping section, steps of process mapping, commonly used symbols and benefits of process mapping are summarized. After the process mapping, Fishbone diagram or Ishikawa diagram comes. Case sampling data sets are defined in data collection plan section. After the data collection plan, Pareto analysis part comes. In Pareto analysis part, pareto rules, 80/20 rules and visually example are given.

MINITAB and statistical quality control tools or methods are summarized in last part. In the statistical quality control part covers the normality test, P Value, Cpk values, Two Sample T-Test, CI and process capability definitions.

Summarily, methodology parts provide a mini handbook of tools and methods used in this case study.

3.1 Sigma & Six Sigma Definition

Six Sigma is a data-driven process improvement methodology used to achieve stable and predictable process results, reducing process variation and defects [16]. Six sigma

converts all processes to the continuous improvement processes. Main idea of six sigma is that minimizes defects by reducing variations with 3.4 defect on per million. Purpose is do right at first time. Another critical point of six sigma is the “voice of the customer”. In Six Sigma, output define with customer requirements.

Sigma shown with the Greek alphabet letter is “ σ ”. This letter shows the standard deviation. Six Sigma use the standard deviation for main construction. Standard deviation is an indicator that shows how far data from mean value in statistics rules. In low standard deviation cases, data are closer to mean value, high standard deviation cases, data are away from the mean value. These distance level gives the variations. Six sigma uses one more statistical tool as bell-shaped distribution (for normality) that shows the distribution of all data for the case study. Central of the bell-shaped curve is mean (μ). The peak of the curve presents the mode of the dataset and a bell-shaped curve is based from this situation. Figure 3.1 shows the distributions of the percentages.

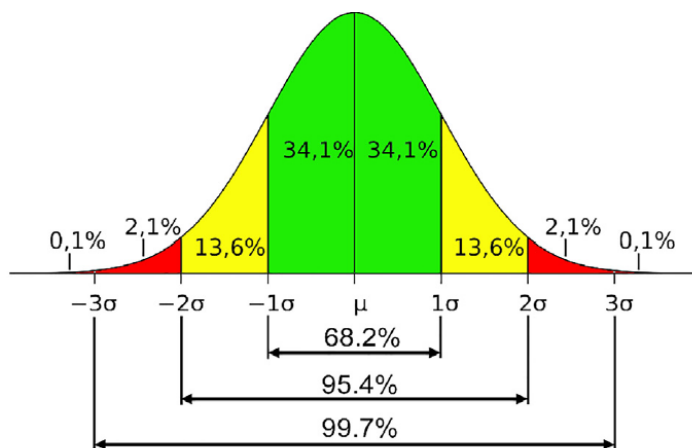


Figure 3.1: Bell-shaped curve.

Source: D.H. Stamatis, *Six Sigma and Beyond*, first ed., ST. Lucie Press, New York, 2003.

Sigma has the quality levels that are related the defects occurrence level. Higher sigma level means the lesser defects. In sigma methodology can be seen different sigma shifts as $\pm 1\sigma$ or $\pm 1.5\sigma$. Today, we use mostly $\pm 1.5\sigma$ shifting. These shifts cover the distribution with statistically- mean of the process is allowed. DPMO- defect on per million is equal to 3.4 defects per million opportunities. 6 sigma means DPMO, but sometimes we can see 3 Sigma that means 66.000 defects per million. 3 sigma has capability for approximately 93.32 percent long-term yield. 4 Sigma is 6000 defects

per million and has 99.38 percent long term yield. 6 sigma has 99.99996 percent long-term yield. Therefore 6 Sigma is mostly used type in sigma methodology with highest yield percentage. Bell- shaped curve shows these distributions via percentages.

There is a mathematical transformation in Six Sigma. Mathematically Six Sigma determine as a transfer function ($y=f(x_1, x_2, \dots, x_n)$). The function defines between quality metrics and inputs. For example, $y=f(x)$ = Excessive production timing, x_1 = Production planning, x_2 = Production capacity etc. There are two critical point is here x_1, x_2, x_n 's effects to "y" is the output metrics and all metrics' upper and lower specification limits (USL/LSL). As we said before the critical thing of six sigma is "voice of the customer". In mathematically, the "voice of the customer" define as CTQ (customer requirements). $y=f(x)=CTQ(y)$. In the final equation $y=f(x)$ covers the meets CTQ via minimizing COPQ (cost of poor quality).

3.2 Six Sigma Methodology

In six sigma implementations have two main methodology which are DMAIC and DMADV. DMAIC (define, measure, analyze, improve and control) is used for existing products and processes. DMADV (define, measure, analyze, design and verify) is used for new products or processes. In today, literature has six sigma methodologies have two branches as defect/waste reduction and cycle time reduction. In defect/waste reduction DMADOV, DMADV, DAMIC, DSSS+ and in cycle time reduction CFPM are defined. Summarily explaining of these types of sigma is: DMADOV- Define, measure, analyze, design, optimize, verify is used in design and manufacturing; DMADV- Define, measure, analyze, design, verify is used in designing new processes; DMAIC is defined and used for improvement of processes; DSSS+ means developing six sigma software and used in software development. In cycle reduction, CFPM defines as cross function process mapping for improvement processes.

All methodologies use for different tools for own processes. In this study, aim is improving processes. Therefore, DMAIC will used. Steps of DMAIC and used tools in each step has been described as a list as following on Table 3.1.

Table 3.1: Steps of DMAIC process.

Steps of DMAIC process	Description	Tools
D Define	- Define customer - Define requirements and customers' expectations (CTQ Statement) - Define needs of project - Define defects (Objective metric) - Define cost of poor quality - Define problem statement, scope and goal - Define processes - Define plan of the project – timeline - Define risks - Define with translation customer requirements to engineering requirements via KPOV metrics	- Project Charter - Voice of the customer - Stakeholder analysis - Survey design - Project plan- timeline - SIPOC Matrices and SIPOC Diagram - Kano Analysis - Process mapping - Communication chart - KPOV Metrics (Primary Metrics-Secondary Metrics)
M Measure	- Measure the processes for CTQ statement - Develop a data collection plan - Root cause definition - Flow of the system - Develop alternatives - Measuring plan - Formulate transfer functions ($F(x) = CTQ(y)$) - Measure CTQ capability-Detailed measurement analysis	- Data collection plan - Fishbone diagram - Flow charts - Failure modes and effects analysis - Quality function deployment - Operational definitions
A Analysis	- Determine variations in the processes - Cause and effect analysis - Priority analysis for improvements - Ranking alternatives- Optimization plan	- Pareto chart - Histograms - Optimization methods
I Improve	- Act alternatives for improvement - Ideal process mapping	- Flow chart - Control plan - Statistical process control
C Control	- Control process variations to CTQ requirements - Monitor improved process and check the sustainability - Implement improvement to the system	

3.3 Voice of the Customer

Customer is the key input of the any processes or products, because customer is the user of outputs. Therefore, core of the projects starts with the customer. According to a study, (based on 243 firms and 14 different industries) customer participation is positively related to new product development performance and that the effect is mediated by innovativeness [17]. Customer voice adds value with customer inclusion in firm governance and psychological ownership [18].

The voice of the customer (VOC) described as customers' needs and expectations for products, services and processes. The voice of the customer is the one of the marketing research techniques. This method brings together customers' expectations and organized in a hierarchical structure. After the hierarchical structure, prioritized them based on relative importance and current alternatives [19]. VOC is worked with qualitative and quantitative methods.

VOC measurement methods are listed as following [17]:

- Survey
- Likert scale- A Psychometric Scale Commonly Involved In Research That Employs Questionnaires.
- Longitudinal data: mail survey, telephone interviews, web searches, and archival data
- Interviews
- Experimental
- Qualitative interviews, biographic histories, and archival documents
- Literature review
- Case studies
- Secondary data – Multiple Choices
- Netnography- Digital Footprint Tracking based on target group

In this thesis, voice of the customer (VOC) is measured with experimental methods. Because, customers of this case study are a little group who are technicians, engineers and test responsible. In the historical data saving step, customers' feedbacks saved.

3.4 CTQ Statement (Critical to Quality)

CTQ (Critical to Quality) means analyzed qualitative data from VOC (Voice of Customer). Customer data turn into qualitative data and after that CTQ is arise. CTQ covers the quality metrics that are chosen in own project scope (so named as dynamical) [19]. The difference between VOC and CTQ is that VOC covers the customers' needed, CTQ covers quality of process to provide customers' needs. For example, silent car engine sound is VOC, needed engine tolerances and production needed are CTQ. Therefore, CTQ defined as qualitative. "VOC and CTQ Relationship Map "give a summary of flow between two of them.

In this thesis, CTQ is defined on processes durations as qualitative based on VOC. Figure 3.2 shows the VOC and CTQ relationship mapping.

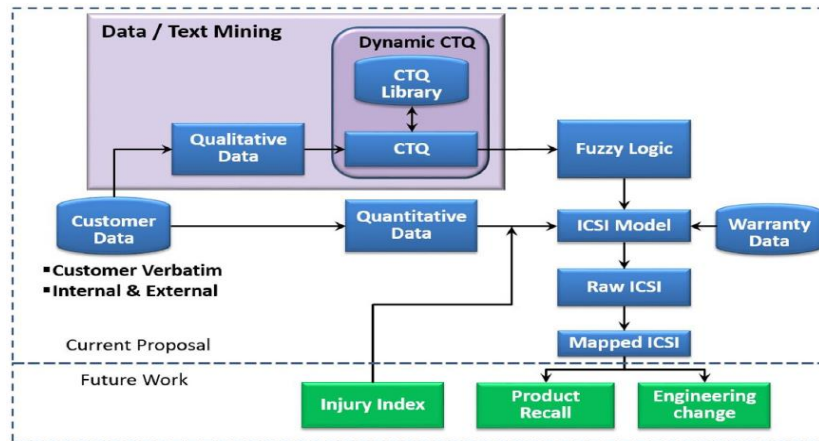


Figure 3.2: VOC and CTQ relationship map.

Source: Celestine Aguwa *, Mohammad Hessam Olya , Leslie Monplaisir,(2017), *Modeling of fuzzy-based voice of customer for business decision analytics*,<http://dx.doi.org/10.1016/j.knosys.2017.03.019>

3.5 Cost of Poor Quality (COPQ)

Cost of poor quality (COPQ) other named is poor quality costs (PQC), it is an expression of the effect of inefficient / inadequate processes or situations on cost.

COPQ was popularized by IBM quality expert H. James Harrington in his 1987 book Poor Quality Costs [20]. COPQ is a refinement of the concept of quality costs. In the 1960s, IBM undertook an effort to study its own quality costs and tailored the concept for its own use [20].

Cost of poor quality is the subtitle of the cost of quality. Cost of quality have main two branches are cost of poor quality and cost of good quality. COPQ has two categories are internal failure costs, external failure costs.

- **Internal Failure Costs:** Internal failure costs covers the before costs of delivered to customers. Wastes, scraps, reworks, failures are the internal failure.
- **External Failure Costs:** External failure costs covers the after costs of delivered to customers. Repairs, servicing, warranty costs, complaints, and returns are external failure costs.

Cost of good quality have two type of costs such as appraisal costs and prevention costs.

- Appraisal Costs: Appraisal costs covers the measuring and monitoring activities costs (Verification, quality audits, supplier ratings).
- Prevention Costs: Product/service requirements, quality planning, quality assurance and training costs are prevention costs.

In Six Sigma, COPQ helps to increase customer satisfaction. In this thesis, COPQ is defined as poor process quality based on higher testing cost- due to longer test durations and inefficiencies.

3.6 SIPOC Matrix and SIPOC Diagram

SIPOC (Supplier, Inputs, Process, Output, Customer) defines stakeholders of processes/improvements. SIPOC is the high-level mapping method for improvement.

- Supplier: The person/process/company that worked in the main process.
- Input: The material or information needed.
- Process: The internal steps (all steps-including have wastes steps).
- Output: Delivered item to customers (CTQ).
- Customer: Final customer of processes.

SIPOC matrix and diagram steps as listed following:

1. SIPOC is started from the end item is “C”-Customers. Voice of customers (VOC) data is analyzed and recorded in “C” box.
2. Second step is “O” box. In this step VOC’s outputs are examined. Key question for this step that “What is important output related your VOC?”. This step refers to $f(x) = Y$ mathematical transformation. Output is called “Y”- definition of defect. There are more than one Y in this step based on customer’s expectations. Outputs have different data types such as continuous, discrete percentage and discrete count.

Continuous Data: Time scales is continuous. For example, cycle time in days, hours, minutes, seconds or money as revenue, expense in price units. Ratio is calculated with dividing continuous data by continuous data are continuous. Formula is % of time = (actual time- time)/time [21].

Discrete Percentage Data: In discrete percentage data set conclude as “acceptable” or “unacceptable”. Formula is “Percentage = Numbers of cases/ Total numbers of orders”. For example, total 100 units are produced, have 20 defective products = $20/100 = 20\%$ [21].

Discrete Count Data: In discrete count data set shows the numbers of attributes. For example, have four tests, but two of them are successful.

This data setting is important for analysis steps. Y measurement classified in this step. In this thesis, we have boxplots measurements and decided what types of graphs in this step. Figure 3.3 shows the data types in main categories.

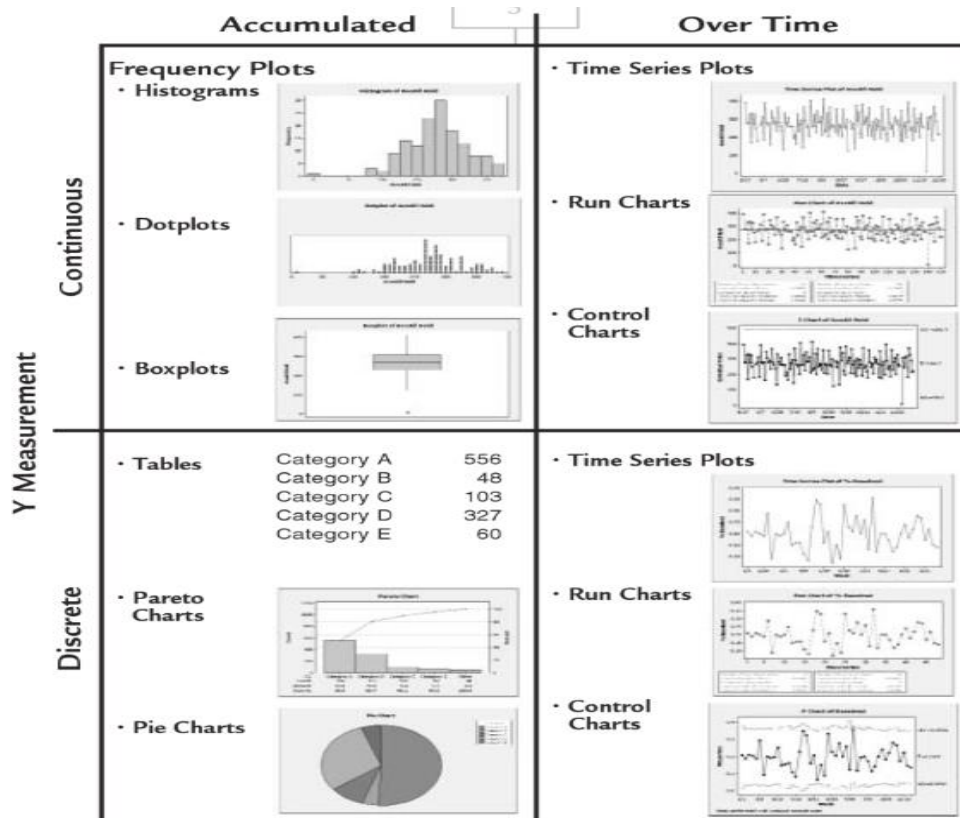


Figure 3.3: Data types.

Source: David Rasmussen, *SIPOC Picture Book: A Visual Guide to SIPOC/DMAIC Relationship*, p.7.

3. “Process” defines overall borders of processes step by step.
4. “Inputs” define material or information in processes.
5. “Suppliers” define needed support as people/process/company in processes.

3.7 Key Process Output Variable (KPOV) Metrics

Key process output variable (KPOV) metrics are the outcome of the SIPOC matrix and diagram. Customers’ essential needs are named as CTQ that returned with outputs. KPOV means these outputs. KPOV metrics are defined with countable targets. KPOVs identified as critical to process stability.

3.8 Process Mapping

Business Process Management (BPM) is the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities [22; p,1]. Process mapping is a visual graphic that shows inputs, outputs and relationships between actions in processes. Aim of the process mapping is creating process flows as graphically at one shot looking. Process mapping have common symbols that based on process types.

Process mapping have more benefits.

- Process mapping simplifies the analysis and understanding of complex systems
- Process mapping helps to identify such as bottlenecks, delays, capacity, constraints
- Process mapping makes easier to manage changes
- Process mapping shows problems related bottlenecks, delays, capacity, constraints easily

Steps of the process mapping:

1. Define aim of the process mapping
2. Select the processes to map
3. Select mapping techniques: Process flowchart or deployment flowchart (cross functional flowchart).

Figure 3.4 shows the flowcharts symbols and Figure 3.5 shows the example of flowchart.

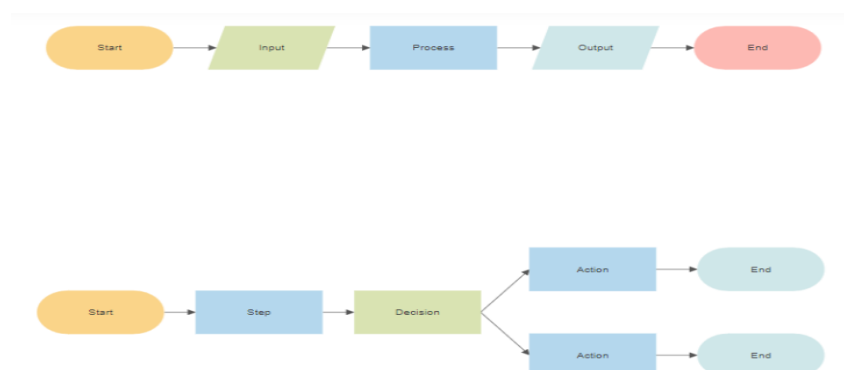


Figure 3.4: Symbols of Flowchart.

Source:URL < <https://www.smartdraw.com/flowchart/flowchart-symbols.htm> > date retrieved 08.05.2020

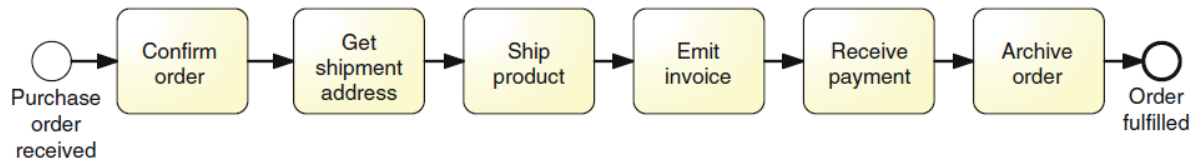


Figure 3.5: An example of process mapping.

Source: Marlon Dumas, Marcello La Rosa, Jan Mendling , Hajo A. Reijers, *Fundamentals of Business Process Management Second Edition*, <https://doi.org/10.1007/978-3-662-56509-4>, ISBN 978-3-662-56508-7 ISBN 978-3-662-56509-4 (eBook)

3.9 Fishbone Diagram

Fishbone diagram or Ishikawa diagrams is the cause and effect diagrams found by Ishikawa [23]. Fishbone (Ishikawa) diagrams mainly represent a model of suggestive presentation for the correlations between an event (effect) and its multiple causes [23]. This diagram creates with brainstorming method.

In the first step of Fishbone diagram, define problem as clearly that is the head of fishbone. After this step, build a framework as a category of problem. For example, problem is delay of assembly (head of fishbone) and main categories of this problem are defined as system, workers, method, materials and etc. In the following step, construct qualitatively identify potential root causes of a specified problem [24].

Main categories and problem show with a node, root causes and main categories linked between as networks. These networks have two types that are one side arrow or two-sided arrow based on relationship type. Figure 3.6 shows the template of fishbone diagram.

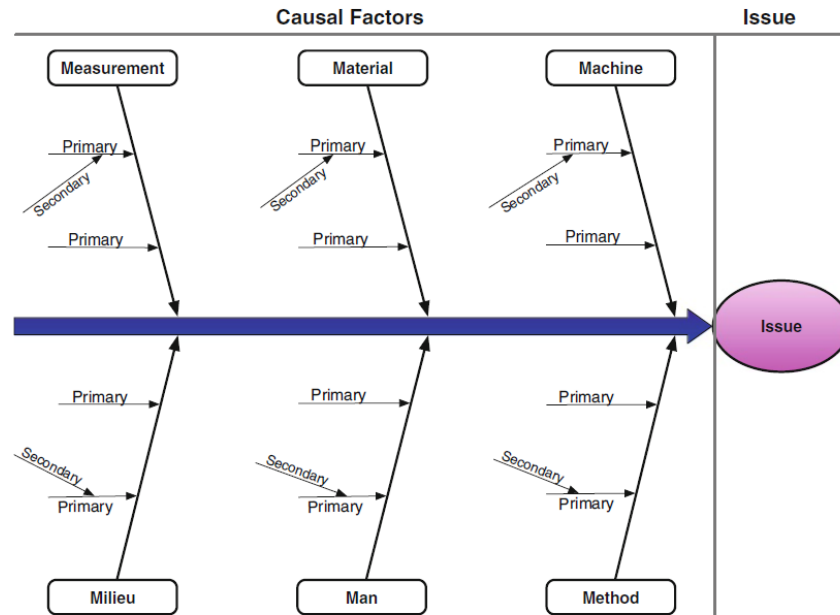


Figure 3.6: Template of a fishbone diagram.

Source: Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo A. Reijers, *Fundamentals of Business Process Management Second Edition*, <https://doi.org/10.1007/978-3-662-56509-4>, ISBN 978-3-662-56508-7 ISBN 978-3-662-56509-4 (eBook)

3.10 Data Collection Plan

Qualitative data collection is the one of the most important things to improvement projects. Because, correct data collection means the true corrective actions and means success of project.

There are different strategies for data collection plan based on aim of the project. Purposive sampling, criterion sampling, theoretical sampling, convenience sampling, snowball sampling, maximum variation sampling, extreme case sampling, typical case sampling, confirming and sampling are the sampling types for data collection [25].

In this thesis, case study is the core concept of the project. Therefore, extreme case sampling and typical case sampling mixing was chosen in the case study side. In the voice of customer section, experimental interview was chosen as said before (in VOC part). Summarily sampling data collection definitions that:

Extreme case sampling: Selection of the most unusual cases [25].

Typical case sampling: Selection of the most typical or average participants [25].

3.11 Pareto Analysis

The principle was developed by Vilfredo Pareto, an Italian economist, and sociologist who conducted a study in Europe in the early 1900s on wealth and poverty [26]. Pareto principle is named as other is ‘vital few and trivial many’. Pareto analysis is a total quality management tool which is statistical term. Pareto’s 80/20 rule has been found to correspond to a normal or Gaussian distribution with a standard deviation that is twice the mean [27].

Pareto 80/20 rule is used in decision making techniques. Core point of Pareto principle in decision making is that 20% of the work, 80% of getting benefit. The Pareto diagram one of the key tools used in total quality control and Six Sigma. Pareto helps to quick route for attacking to improve processes/services/products. All problems are listed, ranked easily with pareto analysis. Pareto chart is important tools to identify the wastes. Pareto chart and analysis are used in vary of industries. Pareto analysis helps to find wastes and their major and minor contributors. Therefore, variations are found easily as parameters.

80/20 rule examples are listed as following:

- 80% of product complaints come from 20% of products.
- 20% of sales 80% of getting revenues.
- 20% of a systems defects cause 80% of related problems.

Pareto analysis have main 4 steps. Examples and detailed explanations have been listed in following:

1. Firstly, define steps and these steps’ wastes description, frequency and wastes. Table 3.2 shows the case study activity durations.

Table 3.2: Example activity information table.

Activity	Waste Description	Frequency	Waste-Mins	Total Waste-Mins
Assembly	Lack of equipment	3	15	45
Painting	Dye house queue	1	5	5
Transport	Delay of packaging	2	10	20

2. Secondly, arrange based on highest cause importance first (percentage calculation). Table 3.7 shows the actions of case study's distribution as percentages.

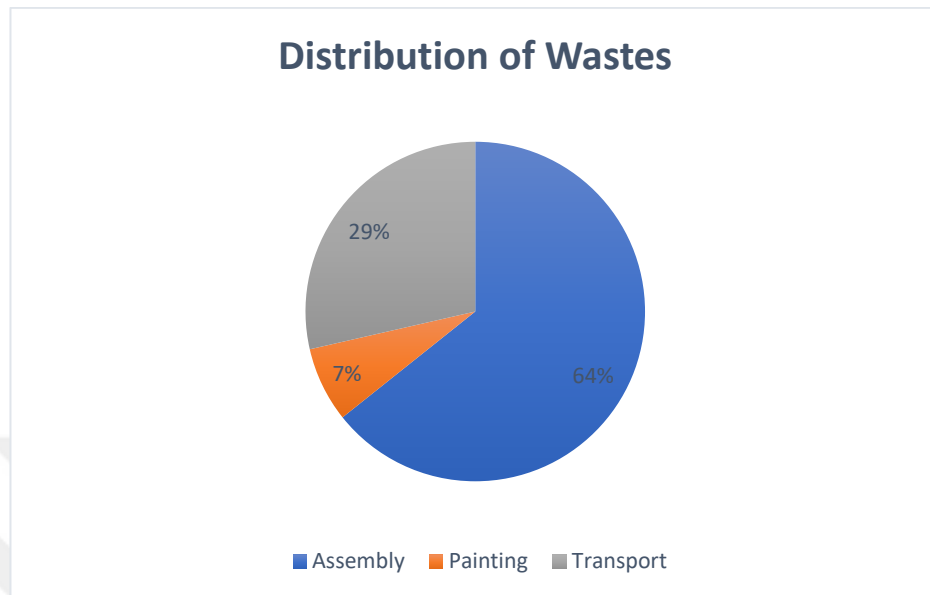


Figure 3.7: Pie-chart of waste distribution.

3. Thirdly, Pareto chart for major wastes with real wastes (mins-blue columns) and percentages (orange line). Figure 3.8 shows the final pareto chart of the case study.

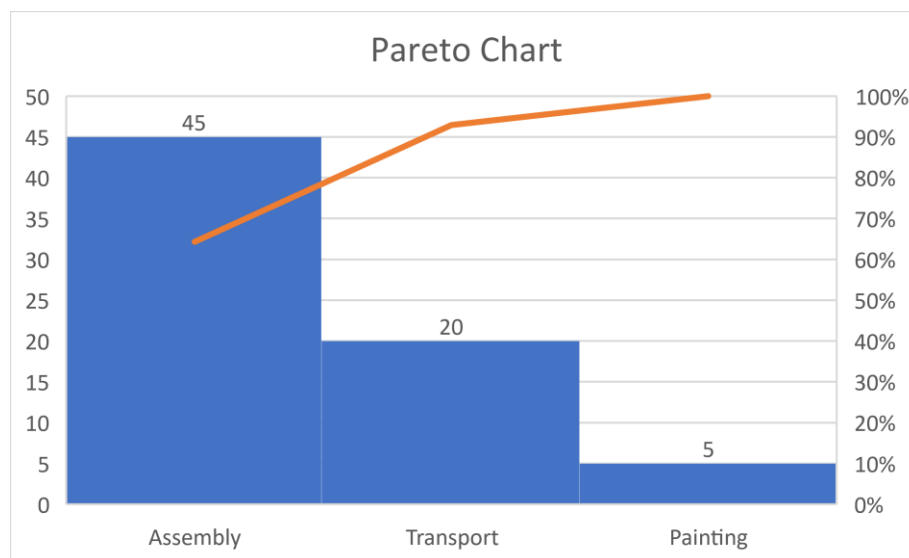


Figure 3.8: Pareto chart example.

4. Make an 80/20 analysis. Red line shows the 80% and focus on top of this line for improvement. Important causes on the left (vital few) from the less important

causes on the right (trivial many) [26]. Figure 3.9 shows the 80/20 analysis of the case study.

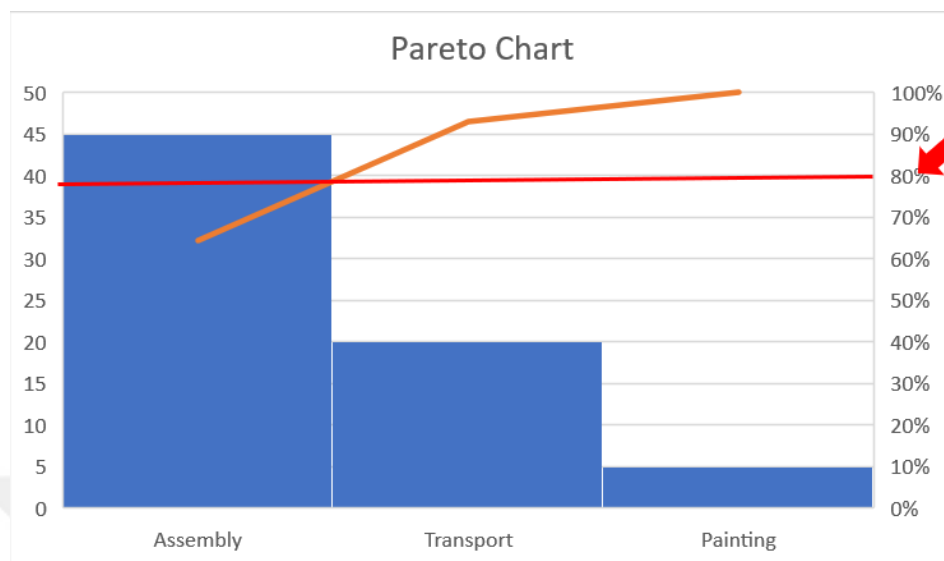


Figure 3.9: Pareto chart example with detailed.

3.12 MINITAB

MINITAB is a general statistics software application. There are many statistical application programs such as SPSS (Statistical Package for the Social Sciences), R Project, STATA, SYSTAT, SAS (Statistical Analysis System), STATGRAPHICS, MATLAB, EVIEWS, NCSS, JMP, JASP, PSPP etc.

MINITAB mostly used in six sigma applications and quality improvements to data analysis, data verification, data visualization. MINITAB is used in many industries with global brands. American Express, General Electric, IBM, McDonald's, Microsoft, Nike, PepsiCo, Royal Dutch Shell, Toyota Motor, Walt Disney and Ford Motor Company are the customers of the Minitab Statistical Software [28].

MINITAB has customers some cases in the own webpage. For example, Boston Scientific is the customer of MINITAB Statistical Software [28]. Boston Scientific is the one of the world's largest developers, manufacturers, and marketers of medical devices. In the MINITAB web site this organization's six sigma case study used Minitab. Case study is that evaluate the pouch-sealing process in-order-to define optimum process conditions and reduce material costs at the Heredia, Costa Rica site. Results of qualified data analysis, Boston Scientific saved more than \$330,000 with

new pouch [28]. Figure 3.10 shows the Boston Scientific used Minitab screens example.

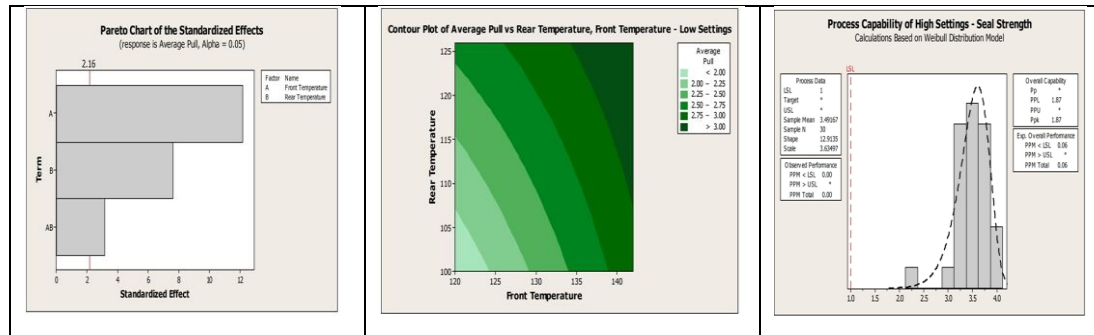


Figure 3.10: Boston Scientific Minitab screens.

Source: URL < <https://www.minitab.com/en-us/Case-Studies/Boston-Scientific/>> date retrieved 01.06.2020

MINITAB have user-friendly screens and so easily run the processes. MINITAB also supports many advanced methods. MINITAB have quality, reliability engineering, product development, business analytics, and process validation tools. In this thesis, process validation section is used. Process validation section process capability, control charts, acceptance sampling, measurement systems analysis screens were used. Figure 3.11 shows the capability main titles of MINITAB.

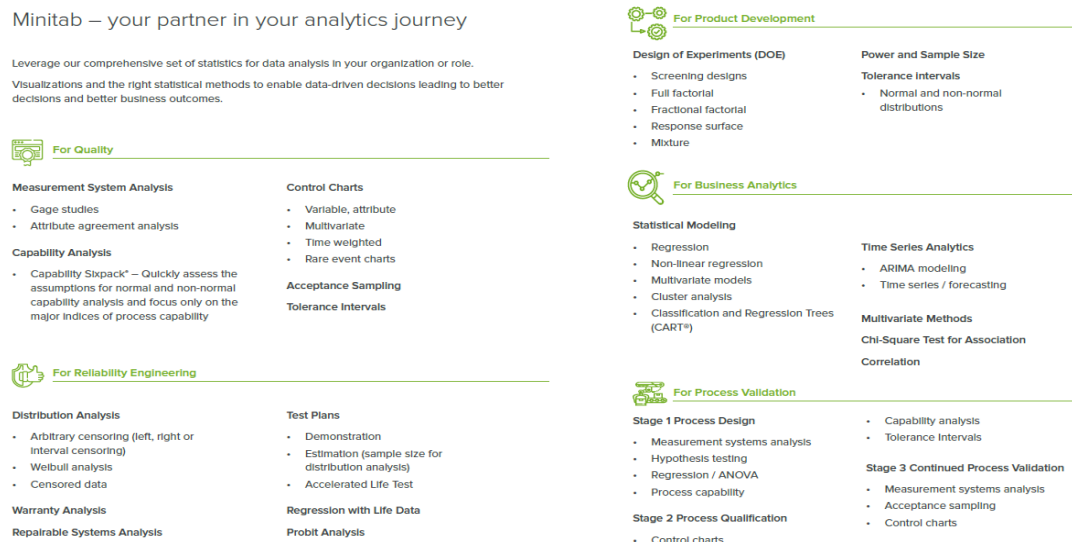


Figure 3.11: Capability of MINITAB.

Source: URL < https://www.minitab.com/uploadedFiles/Documents/Brochures/Minitab-Brochure_EN.pdf> date retrieved 08.05.2020.

3.13 Statistical Quality Control

Quality is defined as “satisfying requirements related aims of business/products” basically. Quality gives an advantage to companies in competition business area. As stated previously on COPQ section, poor quality affects as arising cost and decreasing satisfaction of customers. Statistical methods help overcome the barrier to variation in quality. In this step, statistical quality control and its statistical techniques help to measure, analyze and improve quality.

Summary history of statistical quality control techniques is:

- *Control Charts: was introduced by Dr. Walter Shewart in 1924 at Bell Laboratories.

- * Acceptance Sampling techniques were developed by Dr. H. F. Dodge and H. G. Romig in 1928, also at Bell Laboratories.

- * Design of Experiments developed by Dr. R. A. Fisher in the U.K. began in the 1930s.

Quality control methodology figured in following table. In this thesis, these steps of the quality control methodology are used. Firstly, customer requirements are collected with “Voice of Customer (VOC)” and transformation to technically with SIPOC, COPQ, CTQ. Final output of this step was stated as KPOV metrics and goals.

Secondly, data collected and analyzed. In this step, tolerances (upper and lower specification limits (USL &LSL)) and process capabilities were controlled with control charts that is one of the statistical control tools.

Thirdly, after the analysis of the process capability optimum process level is determined and actions are planned with pareto charts to decrease the variation.

The last step is new setting process control. In this step, control charts, normality tests, two sample T-Tests and process capability are checked again with new process’ dataset. Figure 3.12 shows the “Quality Control Methodology” flowchart.

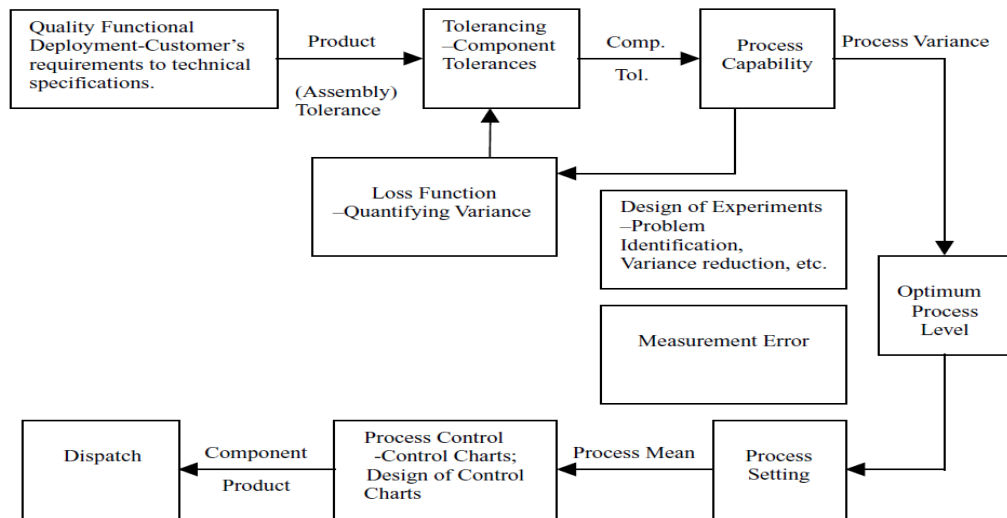


Figure 3.12: Quality control methodology.

Source: Chandra, M. (2001). *Statistical Quality Control*. Boca Raton: CRC Press, <https://0-doi-org.divit.library.itu.edu.tr/10.1201/9781420038675,p,2>.

Summarily, using statistical quality control methods provide satisfactory, dependable and economic quality from our processes and those of our suppliers [29; p,5]. These methods enable us to gain economical control of process by finding and eliminating the causes of poor quality [29; p,5].

3.14 Description of Data

Numerical data has the two main features as average of the numbers and variability among the numbers. Statistical quality control needs numerical data set.

3.15 Control Charts

Control charts invented by Dr. Walter A. Shewhart of the Bell Telephone Laboratories in 1924. Dr. Walter published practical application and economics of control charts in 1931[29; p,73]. Control charts are tools of the analysis and improvement for processes.

There are two purposes of control charts. First purpose is analyzing past data for control. Homogeneity control is realized for the first purpose. Statistically, “N” samples’ variations and stability are checked in control limits. Second purpose of the control charts is to compare results [30; p,32]. Figure 3.12 shows the an example of data distribution.



Figure 3.13: Data distribution example.

Source: Burr, I. (1976). *Statistical Quality Control Methods*. New York: Routledge, <https://doi-org.divit.library.itu.edu.tr/10.1201/9780203738528,p,24>.

Sample record chart is the beginning step of the control charts. Number of samples shows with “N”. Record charts are named different titles are boxplot, data distribution table etc. Bar charts, line charts, pie charts and other same examples of Excel graphs helps to visualization of the data.

In this thesis, boxplot graph is used. Boxplot graph have 5 elements are upper value, lower value, first quartile line, median, and third quartile line. Range shows the line between upper and lower values. Target of the boxplot graph is that explicate data related its distributions. If the median is located on mid center of the first and third quartile, we can say that normal. Table 3.3 shows an example data and Figure 3.14 shows the these data’s boxplot.

For example, following table have n data set to form a box-plot.

N (Number of samples) = 3

Upper values of Series (1,2,3) = 47, 128, 44

Lower values of Series (1,2,3) = -28, -28, -24

Median means dividing the ranked numbers in the middle side.

Median of Series 1 = -28, -24, -24, -10, -7, 10, 11, 36, 47 = -7

Median of Series 2 = -28, -12, -6, -3, 1, 10, 22, 34, 128 = 1

Median of Series 3 = -24, -19, -3, 4, 11, 27, 27, 34, 44 = 11

Table 3.3: Example table for a case study.

	Series 1	Series 2	Series 3
Category 1	-7	-3	-24
Category 1	-10	1	11
Category 1	-28	-6	34
Category 1	47	10	-19
Category 1	11	34	4
Category 1	-24	128	27
Category 1	-24	22	27
Category 1	36	-12	-3
Category 1	10	-28	44

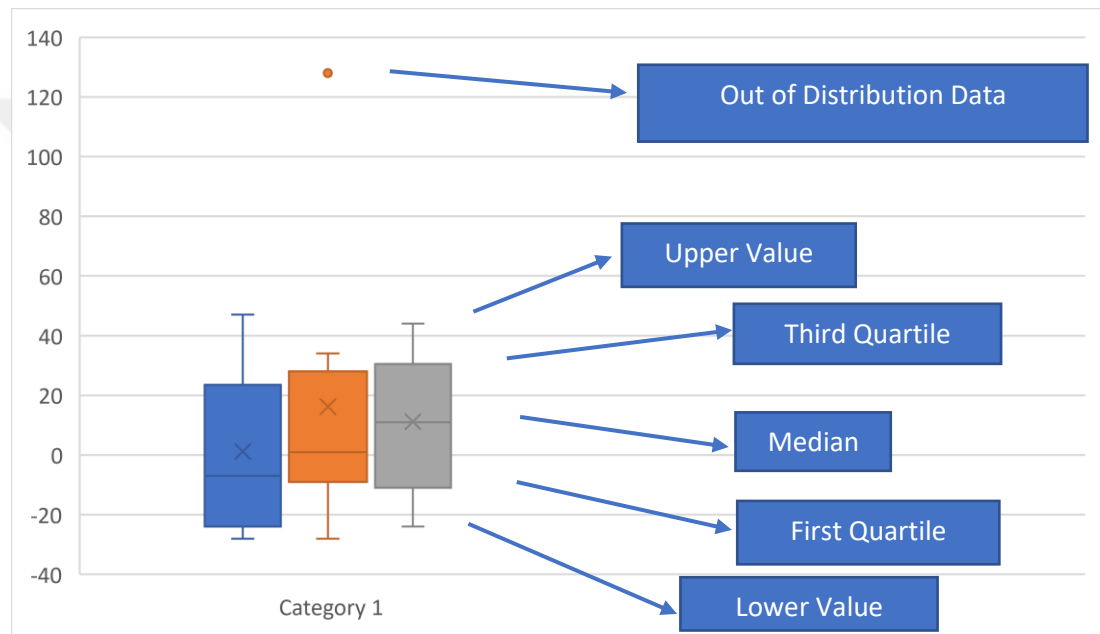


Figure 3.14: Boxplot chart example.

3.15.1 Normality Tests

In this step, we analyze whether the data set obtained quantitatively has normal distribution. The normality test is required to perform all linear studies. If the data set does not pass the normality test, non-parametric studies are required. There are some different types of normality tests: Kolmogorov-Smirnov (K-S) test, Lilliefors corrected K-S test, Shapiro-Wilk test, Anderson-Darling test, Cramer-von Mises test, D'Agostino skewness test, Anscombe-Glynn kurtosis test, D'Agostino-Pearson omnibus test, and the Jarque-Bera test. Minitab Statistical Software offers three tests for Normality: Anderson-Darling (AD), Ryan-Joiner (RJ), and Kolmogorov-Smirnov (KS) [31]. In Minitab, Anderson-Darling (AD) is the best detector for normality tests,

so Anderson-Darling (AD) test is used for normality tests. Figure 3.15 shows the statistical software packages' normality tests are used.

Software	Test									
	SW	SF	KS	LL	CVM	AD	JB	CSQ	RJ	SKKU
SAS	✓		✓		✓	✓				
SPSS	✓			✓						
SPLUS	✓	✓	✓					✓		
STATISTICA	✓		✓	✓				✓		
STATA	✓	✓								✓
STATGRAPHICS	✓		✓	✓	✓	✓		✓		✓
MINITAB			✓			✓			✓	
MATLAB		✓	✓	✓	✓	✓	✓	✓		
R	✓	✓	✓	✓	✓	✓	✓	✓		
IMSL Library	✓		✓	✓				✓		

Notes: SW, Shapiro–Wilk test; SF, Shapiro–Francia test; KS, Kolomogorov–Smirnov test; LL, Lilliefors test; CVM, Cramer–Von Mises test; AD, Anderson–Darling test; JB, Jarque–Bera test; CSQ, chi-squared test; RJ, Ryan–Joiner test; SKKU, skewness–kurtosis test.

Figure 3.15: Normality tests available in statistical software packages.

Source: B. W. Yap & C. H. Sim (2011) *Comparisons of various types of normality tests*, *Journal of Statistical Computation and Simulation*, 81:12, 2141-2155, DOI: 10.1080/00949655.2010.520163

Normality tests can be classified into tests based on regression and correlation (SW, Shapiro–Francia and Ryan–Joiner tests), CSQ test, empirical distribution test (such as KS, LL, AD and CVM), moment tests (skewness test, kurtosis test, D’Agostino test, JB test), spacings test (Rao’s test, Greenwood test) and other special tests [31].

According the researches, AD test is the best for asymmetric distribution [31]. Anderson-Darling test (AD test) is based from CVM (Cramer-Von Mises Test). But in AD test have difference related more weight to the tail of the distribution. AD test has specific hypothesized distribution with critical values. AD test is so sensitive comparison with other normality tests.

AD test statistics’ formula summarized as following:

n = Numbers of Sample

$$AD = n \int_{-\infty}^{\infty} [F_n(x) - F^*(x)]^2 \Psi(F(x)) dF(x),$$

$$AD = - \sum \left[\frac{(2i-1)\{\log P_i + \log(1 - P_{n+1-i})\}}{n} \right] - n,$$

$$AD^* = AD \left(1 + \frac{0.75}{n} + \frac{2.24}{n^2} \right).$$
(3.1)

After the selecting test type for normality test, hypothesize step is the next. H0 and H1 are our hypothesis for this working.

H0: X is normally distributed

H1: X is not normally distributed.

Figure 3.16 is an example, following first histogram have S curve is normal and so in first plot, data are on normality line. Second histogram have left shoulder. Therefore, second is non-normal comparison with first histogram. Third histogram have two sided shoulders, and plot have “S” shape.

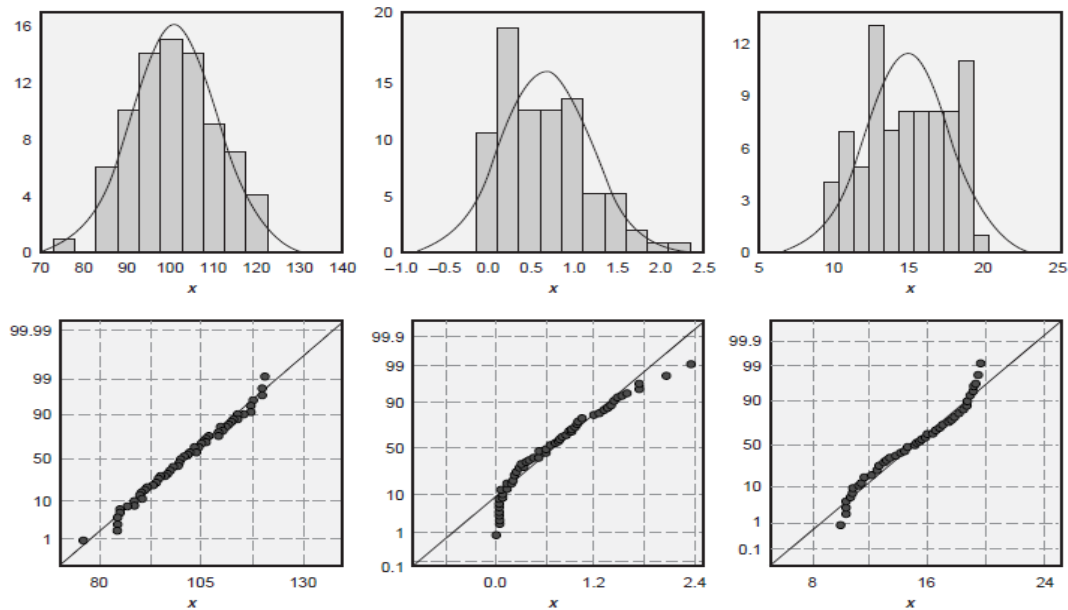


Figure 3.16: An example for normality tests.

Source: Paul G. Mathews (2005), *Design of Experiments with MINITAB*, ASQ Quality Press, Milwaukee, Wisconsin, ISBN 0-87389-637-8, p.76.

“P Value” is the critical for normality tests. If P value greater than 0.05, accept H0: X is normal distribution. If P value is smaller than 0.001 reject H0. ($0.01 < p < 0.05$).

3.15.2 Test for Homogeneity of Variances

In this step, variances homogeneity of data set is check. MINITAB uses ANOVA for this test. All data values record the “Test for Equal Variances” screen and result are shown in the Figure 3.17:

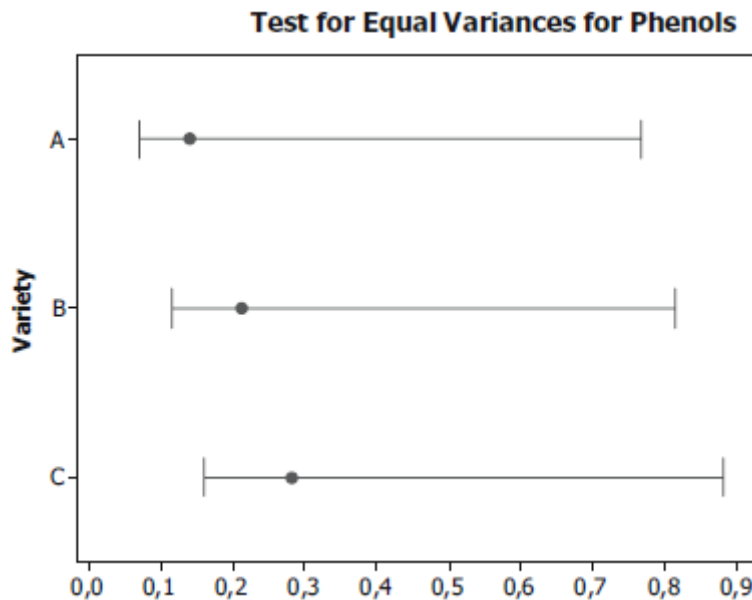


Figure 3.17: An example of test for equal variances report.

Source: Pere Grima Cintas, Lluís Marco Almagro, Xavier Tort-Martorell Llabrés (2012), *Industrial Statistics with Minitab*, 2012 John Wiley & Sons, Ltd, 9780470972755 |Online ISBN:9781118383773 |DOI:10.1002/9781118383773,p,119.

According to “Test for Equal Variances” table, intervals overlap so we can say that variability is different for A, B, C data sets. If intervals do not overlap, we understand the standard deviations different each of them.

3.16 Process Capability

Process capability is related mean and the variance of the distribution of a quality characteristic to the specification/tolerance limits and gives numerical measures of the extent to which the above conditions are met [32; p,84].

Juran, Gryna, and Bingham first proposed the process capability index, Cp [33]. Cp and Cpk are the two most commonly used process capability indexes in the manufacturing industry, which are defined on formulation 3.2 and 3.3 [33]:

Process Capability = 6σ

(3.2)

$$C_p = \frac{USL - LSL}{6\sigma} \quad C_{pk} = \min \left\{ \frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma} \right\} \quad (3.3)$$

In the process capability test, C_{pk} , N (number of sample), μ (Mean), and standard deviation are the critical elements. Firstly, number of sample and data set record on table as following. After, means of these data sets are calculated. Table 3.4 summarized table of process capability.

Table 3.4: An example for process capability table.

	N	Mean	St Dev
Historical Data	5	218,0	55,5
Sample Data	22	170,0	45,1

After this two step, we need an estimate for difference.

Estimate for Difference = μ (Historical Data) - μ (Sample Data)

Estimate for difference: 48,0

USL is the aim of the thesis is record on MINITAB. LSL and target data can be record for this test. Sample mean, numbers of sample, standard deviation(overall), and standard deviation (within) are located left side of report. Standard deviation (overall) defines mathematically variation for all case data set, but standard deviation(within) defines mathematically variation for sub-groups of data sets. These two data are so critical for process capability analyses.

Overall capability and potential(within) capability are located on right side of process capability report. Potential(within) capability shows the sub-groups of data sets' capability, on the other hand overall capability shows the all groups data sets' capability with interactions with each-others. C_{pk} is the most important for us in this step. If $C_{pk} > 0$, process is capable, $C_{pk} < 0$, process is not capable.

Figure 3.18 shows the performance table. First line shows the $PPM < LSL$ means that expected results in lower than lower specification limits. Observed columns shows the numbers of case studies have $PPM < LSL$ condition. Expected overall columns shows the expectation related numbers of case studies have $PPM < LSL$ condition in overall

process during. Expected within shows the expectation related numbers of case studies have $PPM < LSL$ condition in only specific sub-process during. If these numbers will be “0”, we can say that process is steady.

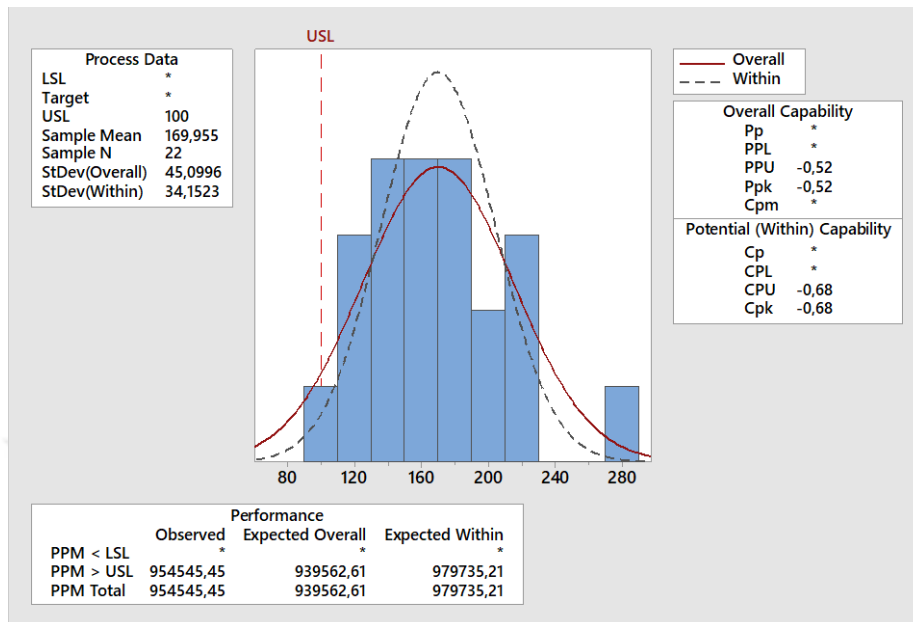


Figure 3.18: Process capability report example.

Summarily, methodology part covers the used tools' explanations in the thesis. Six sigma and its definition are given at firstly. Six Sigma have the highest yield percentage that 99.99996 percent long-term efficiency in quality levels. Therefore, six sigma methodology is the most used for improvement projects. In this thesis, six sigma methodology was preferred due to both process improvement and the process characteristics of sigma close to perfection.

Second part of the methodology describe the six sigma methodologies as DMAIC, DMADOV, DMADV, DAMIC, DSSS+ and in cycle time reduction CFPM. All six sigma methodologies are designed for different purposes. Since our thesis topic is process improvement, DMAIC methodology was preferred. All the tools used by the DMAIC methodology are mentioned in the methodology section and used in the thesis.

In the next sections of the thesis, DMAIC tools are proceeded with the selection of the most suitable tools for based on the thesis topic.

In the “Define” step used voice of customer, SIPOC matrices and SIPOC diagram, process mapping and KPOV metrics (Primary and secondary metrics). Voice of the customer tooling is used to define customers and customers' expectations. Needs of

the project is based from voice of customer tools' results. In this thesis, customers are technicians, engineers and test responsible. Voice of the customer is constituted via experimental methods that is real time measurement. CTQ statement (Critical to quality) is transformation of voice of customers as qualitative data. In this thesis, we need qualitative data and so chosen CTQ methods to transformation. COPQ (Cost of poor quality) is a definition of cost based inefficient processes/situations or products. COPQ is defined in this thesis to fully meet customer satisfaction. It is included as an added for the exact determination of the borders. The SIPOC matrix and diagram are used to identify all stakeholders of the processes. It is an advantage to be used in multi-stakeholder projects. Since there are more than one sided stakeholder and interwoven processes in this thesis, SIPOC matrix and diagram are used to separate this situation. KPOV metrics are a combination of both VOC and CTQ. KPOV metrics are summarized information combined with past used tools. Process mapping is a tool that provides us with the input and output of complex systems in a stream. Thanks to process mapping, process delays, bottlenecks and inefficiencies can be easily analyzed. The subject of this thesis is a process improvement. For this reason, process mapping was used. While process mapping is used at the beginning of the thesis for a good understanding of the current process, it is used to show improvements and updates in the analysis and application section of the thesis.

In the "Measure" step, data collection plan, fishbone diagram is used for better and convenient measuring. Fishbone diagram, also known as the Ishikawa diagram, is a tool that provides a cause-effect relationship. In the fishbone diagram, the problems are listed under the main categories. Thus, all problems are listed at a first-looking. Qualitative data is of great importance in process development projects. Data collection plans vary according to the content of the projects. In this thesis, case study measurements and their results are the main dataset. For this reason, the data collection plan is designed as case study outputs.

In the "Analysis" step, pareto chart is used. Pareto analysis is a quality management tool. While doing Pareto analysis, 80/20 rule is applied. This analysis says that if we focus on only 20% of the actions that should be taken while trying to improve a process with the 80/20 rule, we can have an opportunity of 80% improvement. In this thesis, we have many actions to improvements, but we need fast and efficient action route. Therefore, Pareto analysis helps in this step. Second phase of "Analysis" step,

MINITAB applications are control charts, normality tests are used. In this section, collected data is analyzed. Firstly, normality tests are implemented on collected data and processes capabilities measured as not capable. These are the statistical process control tools.

In the “Control” steps, statistical quality control tools are used. Normality tests and process capability tests are used in mostly. Control steps cover the after of improvement actions. So, we check the results of six sigma at this stage.

In summary, we have realized the thesis on the implementation of the Table 3.5 objectives in the process improvement steps and getting the results.

Table 3.5: Project objectives with six sigma vision.

Project Objectives with Six Sigma Vision		
*Reduce defects	*Improve customer satisfaction	*Added value to process/products
*Reduce wastes	*Reduce variation	*Maximizing profit
*Improve efficiency	*Improvement continuity	

4. ANALYSIS AND RESULTS

The thesis "A Process Improvement of Facility Test Efficiency with Six Sigma Methodology in Automotive Industry" is a process improvement thesis. The purpose of the thesis is based on the expectations of the stakeholders of the relevant test processes, focusing on bottlenecks and inefficiencies. The thesis was made by analyzing with real time measurements over the case study.

Facility Test Efficiency Improvement case study arise from high rates of variations on durations of automotive tests. Users of this system (internal and external all customers) says that durations and its variation shall be decreased. These durations and variations cause the cost of poor quality as higher testing costs and wasting times, lower efficiency. Therefore, problem statement, scope and goal are determined as facility tests duration shall be decreased by optimizing change on processes with Six Sigma methodology.

In this case study, firstly define wastes and variations as measurements. Therefore, 22 tests are chosen and measured. Historic data also shows similar results. Data divided into two groups for better analysis. 1st phase covers the preparing test steps, 2nd phase covers the test steps.

Voice of the customer: Test durations (1st phase and 2nd phase) takes too much time. The duration variates depending on the issues arisen. This duration and its variation shall be decreased.

CTQ Statement (Critical to Quality): Testing shall be no more than 100mins for all test processes.

Defect Definition for Y (Objective Metric): 1st phase and 2nd phase of tests durations

Cost of Poor Quality: Poor process quality causes higher testing cost. Due to longer test durations. Unable to fully support programs with efficiency.

Problem Statement, Scope, And Goal: Tests duration shall be decreased by optimizing change on 1st phase and 2nd phase.

Test facility has one test room and one test controller room. Test room has only one vehicle capacity. All roll tests (non-emission tests) and emission tests actualized on this dynamometer. Test room has temperature control system and fans (preconditioning, test temperature),rolls that simulated road conditions, vehicle

connection equipment that is immobilize the vehicle on rolls during the tests, emission measurement components that measure if requested emission tests ,based on requested measure type (bag, prob connection, RDE(sec by sec) and gas measure (CH₄,CO,CO₂,Microsoot,NO,Nox,O₂), additionally has sensors that motion sensors if test vehicle run off roads ,these sensors shut down the system and temperature sensors that controls desired temperature is appropriateness.

Two facility technicians and an engineer help to run tests and control test parameters with computers and screens. Engineers and technicians communicate with control room with walkie-talkies during the tests.

Processes summarized as follows:

1. Tests planning
2. Test vehicles drive to test room
3. Rolls get set test vehicles (wheelbase, length of vehicle)
4. Test vehicle is immobilized with connection equipment
5. Provide the necessary conditions (air temperature, test data, road loads... etc.)
6. Run the tests
7. Disassemble the test vehicle from rolls

4.1 SIPOC Matrix (Supplier-Inputs-Process-Outputs-Customer)

SIPOC (Supplier, Inputs, Process, Output, Customer) defines

- Supplier: The person/process/company that worked in the main process.
- Input: The material or information needed.
- Process: The internal steps (all steps-including have wastes steps).
- Output: Delivered item to customers (CTQ).
- Customer: Final customer of processes.

SIPOC of the thesis has been listed as below with Table 4.1 and Table 4.2:

Table 4.1: SIPOC matrix.

Supplier	Inputs	Process	Outputs	Customer
Technicians	Vehicle	1 st phase of tests	Test data	Test responsible
Engineers	Test information	2 nd phase of tests		
	Test responsible Technicians	Tests		
		Post tests		

Table 4.2: SIPOC diagram.

Supplier	Inputs	Process	Outputs	Customer
Share calendar with Technicians	Meet all request			Planning tests
Check the test information	Schedule tests			Request the tests
Prepare the test & vehicle	Share with data with engineers			
Run the tests	Run tests			

4.2 KPOV Metrics of Case Study

Primary Metric: 1st phase and 2nd phase of testing processes shall be as following
Table 4.3 :

Table 4.3: Metrics of project processes.

	Current Situation	Goal	
1st phase of testing	05:45:36	01:00:00	1st phase of testing
2nd phase of testing	02:14:52	01:30:00	2nd phase of testing

Secondary Metrics: Decreasing waste times on all processes.

4.3 Process Mapping of Case Study

After the gathering data and set the KPOV metrics, processes are defined, and mapping as follows. This process map is named real process mapping. Because, after the optimization processes, need getting optimized process mapping. Figure 4.1 shows the process mapping that “Blue: 1st phase of testing, Orange: 2nd phase of testing, Red: Testing”.

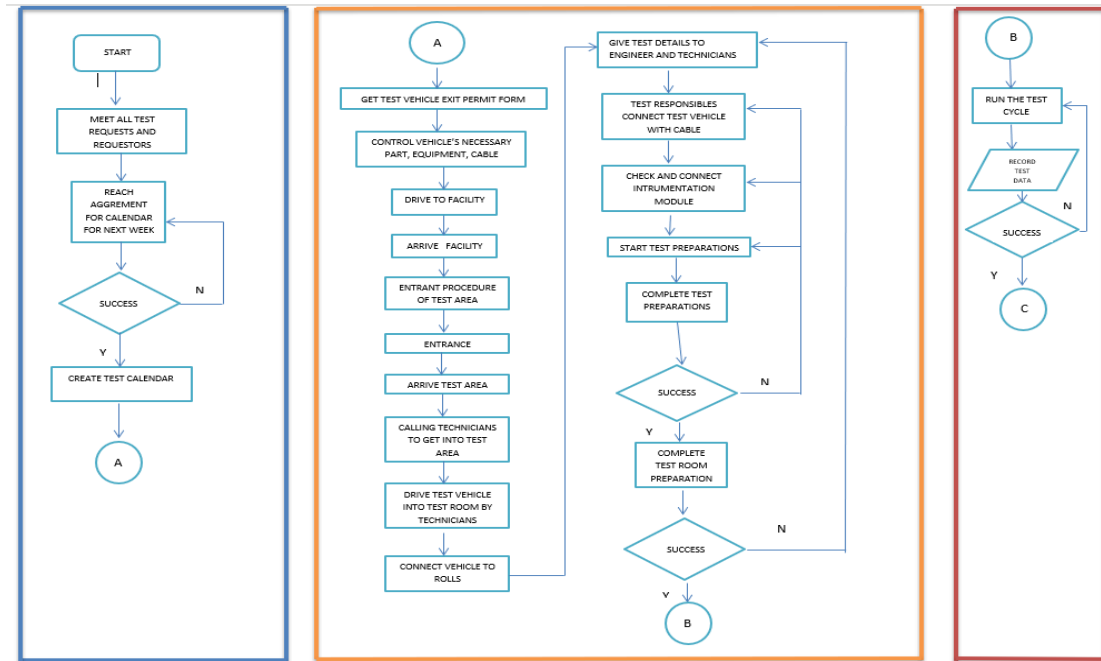


Figure 4.1: Process map of before improvement.

4.4 Fishbone Diagram of Case Study

In the root-cause analyze, fishbone diagram is worked. In five categories as management, method, materials, people and system sides are analyzed, and root causes are defined to waste time reasons.

Management, method, materials, people, and system are the main categories for the waste time reasons. Figure 4.2 shows the fishbone diagram of the case study.

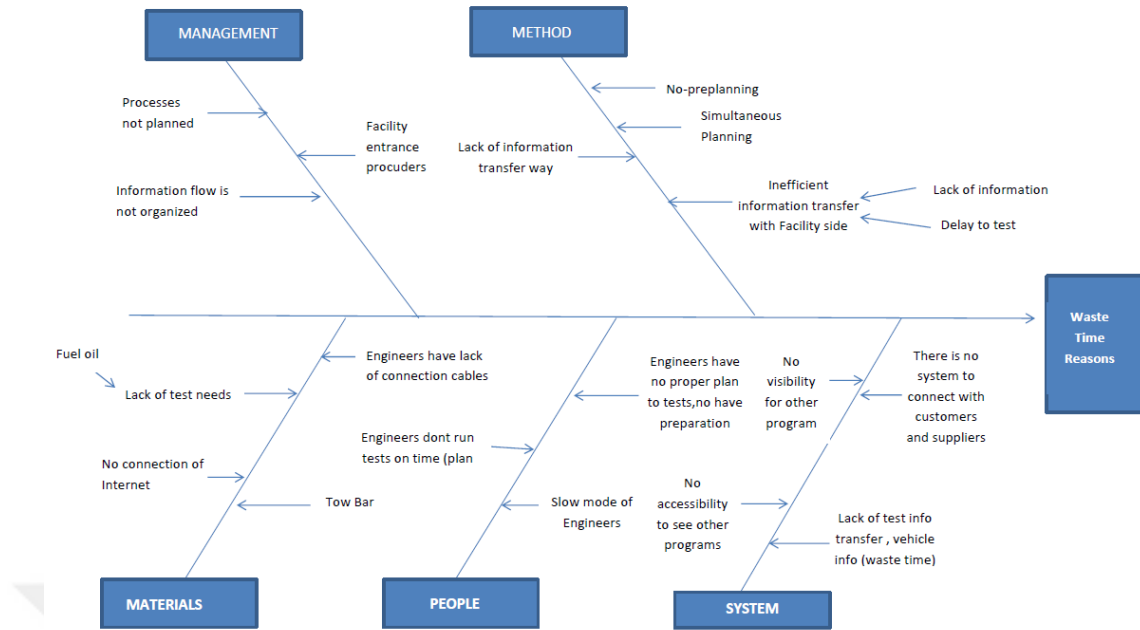


Figure 4.2: Fishbone diagram of the case study.

In the management category, unplanned processes, unorganized information flow and difficulty of the facility entrance procedures are located. Information flow and process managers for all steps before, during and after the test were not clear and planned. This led to the blockage of the process each time, causing inefficiencies and creating failed and costly tests. Test activities are realized at a separate company. For this reason, it is important that the correct information flow to the test location and the officers. In the first phase of the process, this information flow was not organized and sometimes there were situations such as missing information and sometimes no information flowing. For this reason, sometimes results such as the tests not being performed or being performed incorrectly were obtained. The test facility is in a different location as we mentioned earlier. For this reason, test vehicles and test responsible must go through a series of procedures when entering the test campus. This procedure is operated regardless of whether the test campus has previous records but is not available and causes loss of time.

In the method category, there are four main problems titles as lack of transformation transfer way, no preplanning, simultaneous planning, and inefficient information transfer with test facility side. The lack of information flow transfer is that it is unclear which channel to transmit important information, such as when to test, and which tools. Since the lack of preplanning leads to chaotic situations and confusion, inefficiency

causes even job losses, therefore engineering time loss and waste test costs. The number of simultaneous plans is also quite high. Since the necessary preliminary preparation cannot be made due to such plans, extra money is required to be paid for the preparation time in the test area. Inefficient transfer of information results in two main results. Delay in tests and lack of information. This problem results in wasted labor hours and wasted test costs.

Lack of test needs, no connection of internet, lack of connection cables and lack of tow bar problems are located on materials main category. It has been observed that some tests that started successfully due to the lack of the test requirements were also interrupted. For example, a vehicle's fuel has run out of fuel in the middle of the test because it has not been checked in advance. Due to this situation, the test was stopped, the vehicle was removed from the test area and had to leave the location to get fuel-oil. This situation led to inefficient hours and costs. Internet access is very difficult within the test area. However, the engineer performing the test during the test must share the instantaneous test data with the company and take a turn. Since it cannot do this during the test, it is expected that the test will be stopped, connected to the internet and this process will be done. In vehicle tests, they need a connecting cable so that test responsible can record the vehicle's information. In some tests, it was observed that the cable not suitable for the vehicle was taken or that the cable was not taken at all. For this reason, the tests were found to be canceled. In this case, the test price is still paid to the test area. Tow bar is required to connect vehicles to the test area. Therefore, it is necessary to make this check on the vehicles before going to the test. Since this control was not made, the wasted hours and wasted costs were recorded.

Slow mode of engineers, lack of proper plan to test and not running on-time tests are related people side problems. The engineers who will perform the test make mistakes in time to reduce the efficiency of the planned tests. Other vehicles can be taken to the test area if they are not there on time for the planned tests, so they have-to wait or finish the test before they start. Sometimes engineers do not realize that they are paid hourly, they take their work very slowly, and the one-hour test can sometimes go up to two or three hours with lost times. In some tests, it was observed that engineers could not give direction the facility test technicians/engineers correctly due to the lack of individual preparation. Due to the lack of proper preparation, the errors were noted in the tests and recorded in the notes that they were dealt with or had to start late.

System problems are listed as: No visibility for other program, no accessibility to see other programs, no system to connect with customers and suppliers, and lack of test information transfer and vehicle information. Lack of system and lack of time schedule of tests cause jams in the test area. For example, if different vehicles from different vehicle programs want to test at X hours a day, they cannot view it from any area. This situation causes a problem both in terms of visibility and accessibility side. The system problems we have mentioned so far can be described as internal side of company. In addition to the fact that the internal information flow is not visible and accessible, there is no system for the information flow with the company and the test facility area. The lack of this information flow systematically leads to a lack of information. For example, since the vehicle information is not transmitted to the test facility area on time, this information is collected when the vehicle arrives, and the test starts after it. This situation also costs money for that preparation hour and the engineering time used inefficiently.

4.5 Pareto Analysis of Case Study

After putting all the causes and ranking them by the most effective one to the least effective one, the actions which need to be taken are identified. The target was reaching 80% improvement in total. Pareto charts below is Figure 4.3 and Figure 4.4 show graphs including and excluding this item.

$Y1=f(x)$ = Excessive 1st phase of test

X1.1: Schedule weekly plan & sent schedule and test details

X1.2: Meeting structure

$Y2=f(x)$ = Excessive 2nd phase of test

X2.1: Facility entrance

X2.2: Getting entrance card

X2.3: Arrive to test area

X2.4: Calling technicians

X2.5: Vehicle acceptance to test area

X2.6: Immobilize the test vehicle to test area

X2.7: Connecting the test vehicle

X2.8: Connecting instrumentation modules

X2.9: Calibration

X2.10: Calling the control room, check last validity

X2. 11: Starting Test



Figure 4.3: Pareto chart of all phases of testing.

1st phase of test X1.1 and X1.2 actions have high frequency and so we have to take action plan related X1.1 and X1.2.

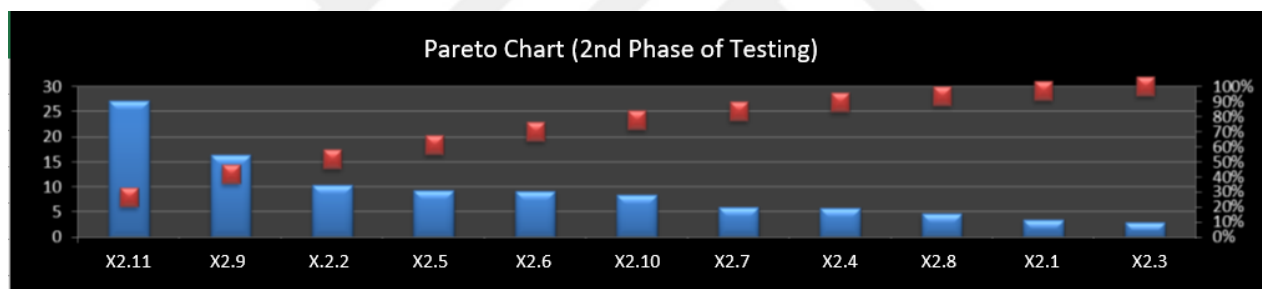


Figure 4.4: Pareto chart of 2nd phase of testing.

According to the pareto chart and analysis, we can focus on scheduling problems on the 1st phase of the test. Facility entrance procedures, information flow and lack of equipment problems are the critical for the 2nd phase of the test. If we focus of the %20 of the problems, we can get the %80 improvements on the processes.

4.6 Data Collection Plan of Case Study

Data collection plan consists of observing tests on facility. Recorded data grouped in two title as historical data that get before 6-sigma project, and sample data that observed and recorded during 6-sigma project. 22 tests are logged as sample data group. 5 tests have recorded as historical data. Figure 4.5 shows the 1st phase of sample data, Figure 4.6 shows the 2nd phase of sample data.

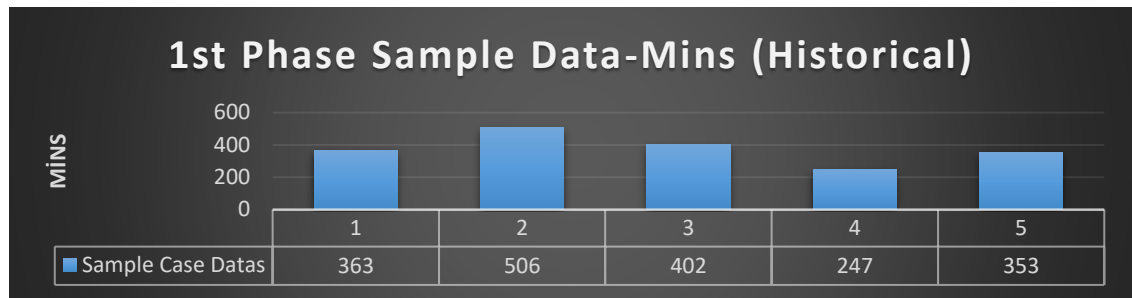


Figure 4.5: 1st phase sample data table.

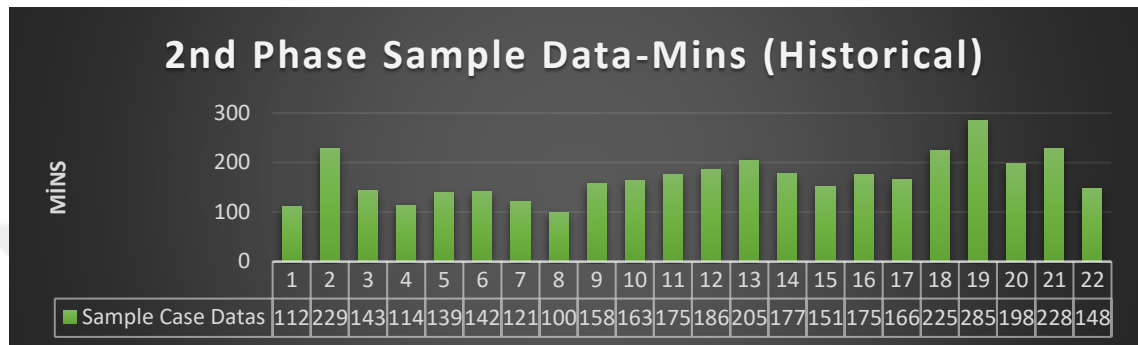


Figure 4.6: 2nd phase sample data table.

4.7 Detailed Measurement Analysis

A detailed time measurement is performed with 22 sample test observation. In 22 sample test, 3 tests are failed. One of failed tests cannot actualize through lack of tow bar. At the other failed test, the vehicle give error on calibration. Facility has down at the other one. It means that the detailed measurement data can be used to identify potential improvement areas.

These samples will be used as a starting point in analysis and key improvement actions.

Table 4.4 and Table 4.5 show the samples durations for 1st phase and 2nd phase of testing.

Table 4.4: Samples duration table for 1st phase of testing.

	SAMPLE1	SAMPLE2	SAMPLE3	SAMPLE4	SAMPLE5	Average
X1.1	01:30:00	00:42:00	00:57:00	00:20:00	01:01:00	0:54:00
X1.2	04:40:00	06:11:00	07:21:00	01:12:00	04:54:00	4:51:36
Total	6:10:00	6:53:00	8:18:00	1:32:00	5:55:00	5:45:36

Table 4.5: Samples duration table for 2nd phase of testing.

	SAMPLE1	SAMPLE2	SAMPLE3	SAMPLE4	SAMPLE5	SAMPLE6
X2.1	00:02:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
X2.2	00:06:00	00:00:00	00:00:00	00:05:00	00:00:00	00:00:00
X2.3	00:01:00	00:00:00	00:00:00	00:02:00	00:00:00	00:00:00
X2.4	00:04:00	00:00:00	00:00:00	00:00:30	00:00:00	00:00:00
X2.5	00:16:00	00:00:00	00:00:00	00:22:00	00:00:00	00:00:00
X2.6	00:11:00	00:00:00	00:00:00	00:29:00	00:00:00	00:00:00
X2.7	00:02:00	01:13:00	00:02:00	00:00:00	00:02:00	00:00:00
X2.8	00:05:00	00:01:00	00:05:00	00:00:00	00:01:00	00:00:00
X2.9	00:00:00	00:35:00	00:03:00	00:06:00	00:00:00	00:17:00
X2.10	00:06:00	00:02:00	00:00:10	00:00:00	00:15:00	00:04:00
X2. 11	00:17:00	00:17:17	00:12:50	00:03:00	00:01:00	00:01:00
	SAMPLE7	SAMPLE8	SAMPLE9	SAMPLE10	SAMPLE11	SAMPLE12
X2.1	00:02:00	00:01:00	00:02:00	00:00:00	00:05:00	00:05:00
X2.2	00:06:00	00:16:00	00:15:00	00:00:00	00:12:00	00:22:00
X2.3	00:05:00	00:01:00	00:02:00	00:00:00	00:03:00	00:03:00
X2.4	00:02:00	00:12:00	00:06:00	00:00:00	00:20:00	00:00:00
X2.5	00:00:00	00:00:00	00:02:00	00:01:00	00:05:00	00:00:30
X2.6	00:00:00	00:15:00	00:22:00	00:19:00	00:45:00	00:19:00
X2.7	00:00:00	00:17:00	00:01:00	00:00:00	00:00:00	00:00:00
X2.8	00:00:00	00:01:00	00:14:00	00:02:00	00:00:00	00:00:00
X2.9	00:06:00	00:02:00	00:05:00	00:06:00	00:00:00	00:08:00
X2.10	00:00:00	00:00:00	00:31:00	00:05:00	00:00:00	00:15:00
X2. 11	00:25:00	00:05:00	00:01:00	00:10:00	00:00:00	00:08:00
	SAMPLE13	SAMPLE14	SAMPLE15	SAMPLE16	SAMPLE17	SAMPLE18
X2.1	00:00:00	00:01:00	00:00:00	00:00:00	00:07:00	00:01:00
X2.2	00:00:00	00:04:00	00:00:00	00:00:00	00:10:00	00:17:00
X2.3	00:00:00	00:10:00	00:00:00	00:00:00	00:03:00	00:03:00
X2.4	00:00:00	00:20:00	00:00:00	00:00:00	00:40:00	00:02:00
X2.5	00:00:00	00:38:00	00:00:00	00:00:00	00:07:00	00:08:00
X2.6	00:00:00	00:18:00	00:00:00	00:00:00	00:22:00	00:32:00
X2.7	00:00:00	00:01:00	00:10:00	00:00:00	00:03:00	00:00:00
X2.8	00:00:00	00:00:00	00:00:00	00:00:00	00:03:00	00:00:00
X2.9	00:07:00	00:16:00	00:00:00	00:00:00	00:03:00	01:43:00
X2.10	00:03:00	00:07:00	00:20:00	00:07:00	00:02:00	00:13:00
X2. 11	03:15:00	00:22:00	00:00:42	00:48:00	00:08:00	00:04:00
	SAMPLE19	SAMPLE20	SAMPLE21	SAMPLE22		
X2.1	00:10:00	00:00:00	00:00:00	00:02:00		
X2.2	00:08:00	00:02:00	00:00:00	00:13:00		
X2.3	00:02:00	00:01:00	00:00:00	00:03:00		
X2.4	00:03:00	00:00:00	00:00:00	00:10:00		
X2.5	00:01:00	01:04:00	00:13:00	00:07:00		
X2.6	00:36:00	00:13:00	00:30:00	00:30:00		
X2.7	00:03:00	00:05:00	00:17:00	00:07:00		
X2.8	00:00:00	00:10:00	00:00:00	00:00:00		
X2.9	00:17:00	00:00:00	00:05:00	00:22:00		
X2.10	00:06:00	00:00:00	00:22:00	00:01:00		
X2. 11	01:37:00	01:04:00	00:21:00	00:10:00		

Table 4.6 is the final table of 22 sample data as summarized on following table. Total time and average time are given for each steps of testing.

Table 4.6: Summarized sample data table.

	Total	Average
X2.1: Facility entrance	00:38:00	00:03:27
X2.2: Getting entrance card	02:16:00	00:10:28
X2.3: Arrive to test area	00:39:00	00:03:00
X2.4: Calling technicians	01:59:30	00:10:52
X2.5: Vehicle acceptance to test area	03:04:30	00:14:12
X2.6: Immobilize the test vehicle to test area	05:41:00	00:24:21
X2.7: Connecting the test vehicle	02:23:00	00:11:00
X2.8: Connecting instrumentation modules	00:42:00	00:04:40
X2.9: Calibration	04:21:00	00:16:19
X2.10: Calling the control room, check last validity	02:39:10	00:09:22
X2. 11: Starting Test	09:30:49	00:27:11
Total		2:14:52

Summary of the sample dataset is 1st phase of testing duration is totally 5:45:36. 2nd phase of testing duration is 2:24:52. And aim of the reduction is summarized on the Table 4.7:

Table 4.7: Metrics of the case study.

	Current Situation	Goal
1st phase of testing	05:45:36	01:00:00
2nd phase of testing	02:14:52	01:30:00

22 tests are 2nd phase of testing ,5 tests are 1st of and testing events are logged. Inefficiencies and waste times observed in 1st and 2nd phase of testing along. Testing time change duration based on contents of test (emission, non-emission, test type, cycle type etc.) . Figure 4.7 and Figure 4.8 show the case data based on 1st phase and 2nd phase.

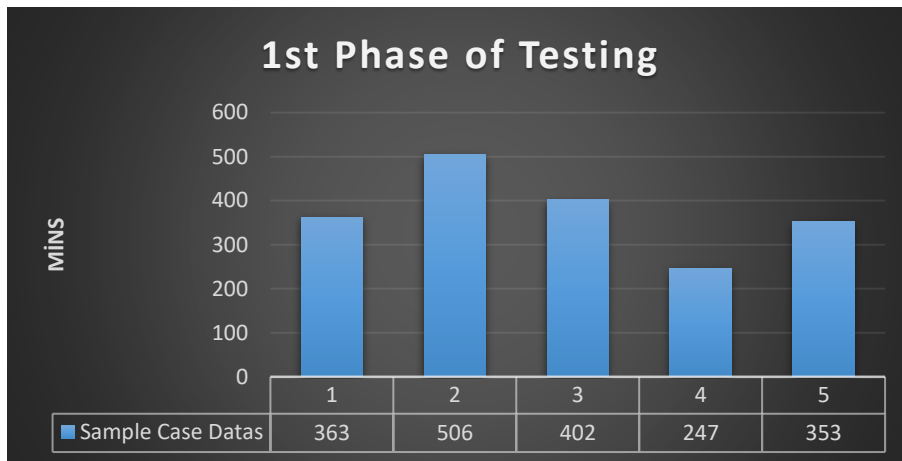


Figure 4.7: 1st phase sample case data.

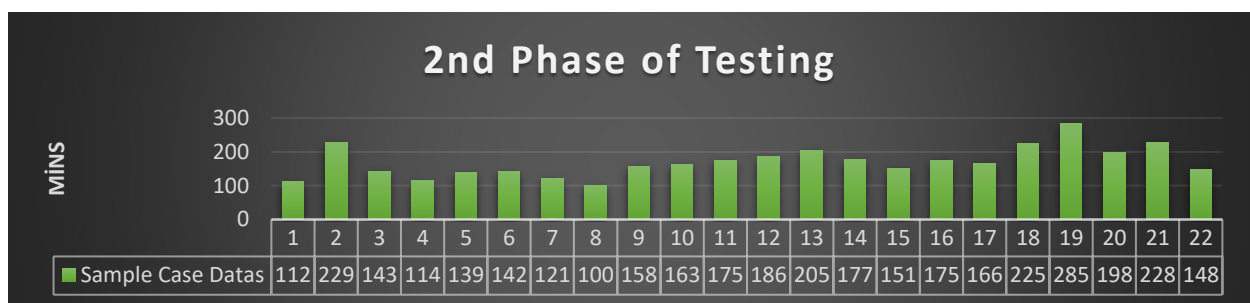


Figure 4.8: 2nd phase sample case data.

4.8 Normality Tests of Sample Data

4.8.1 1st Phase of Testing Data Normality Tests

Historically 5 measurements are logged, and then 5 more measurements are realized as sample data. Figure 4.9 is summary table. Normality tests are needed to ensure for working with validated data. Normality tests worked on Minitab application.

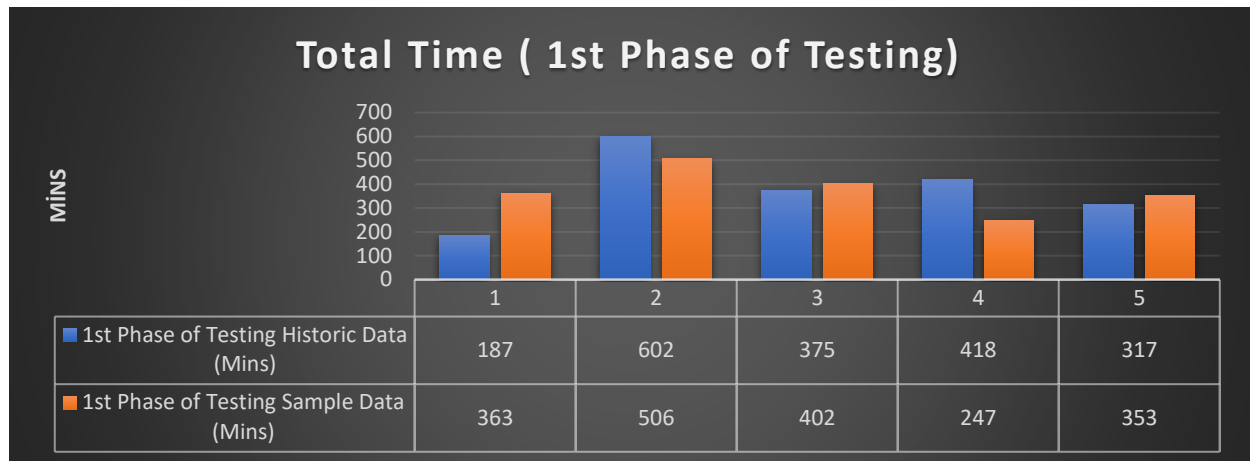


Figure 4.9: Total time of 1st phase of testing.

Figure 4.10 shows the probability plot of 1st phase testing's historical data. P data is critical in this test. P value is 0,781 and means data set is available.

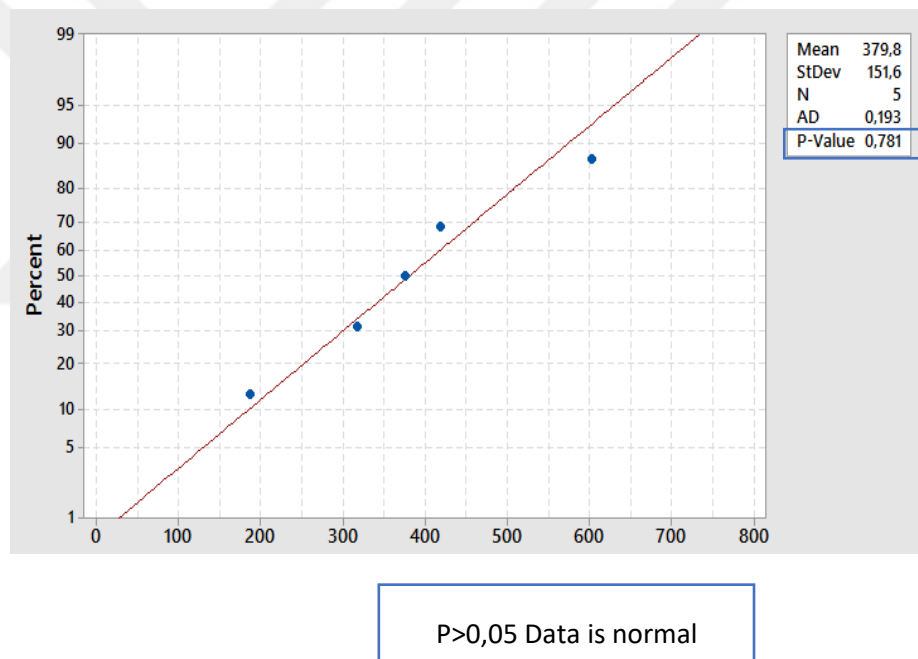
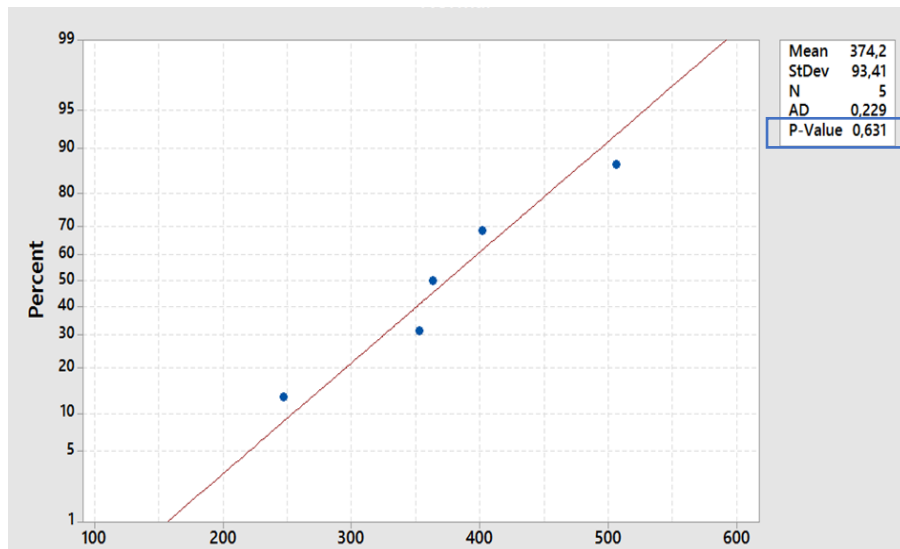


Figure 4.10: Normality test report of 1st phase testing's historical data.

Figure 4.11 shows the probability plot of 1st phase testing's sample data. P data is critical in this test. P value is 0,631 and means data set is available.



P>0,05 Data is normal

Figure 4.11: Normality test report of 1st phase testing’s sample data.

Figure 4.12 and Figure 4.13 shows the variances, distributions and overlapping. In the boxplot, historical data and sample data have acceptable dataset because median line is centered or nearly centered. In the test for equal variances table have overlapping historical and sample data. Therefore, we can study with these datasets.

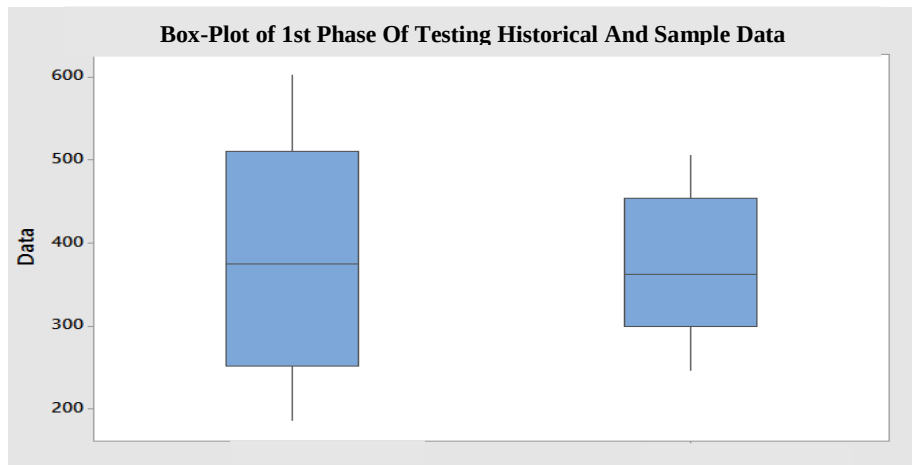


Figure 4.12: Boxplot of 1st phase of testing historical and sample data.

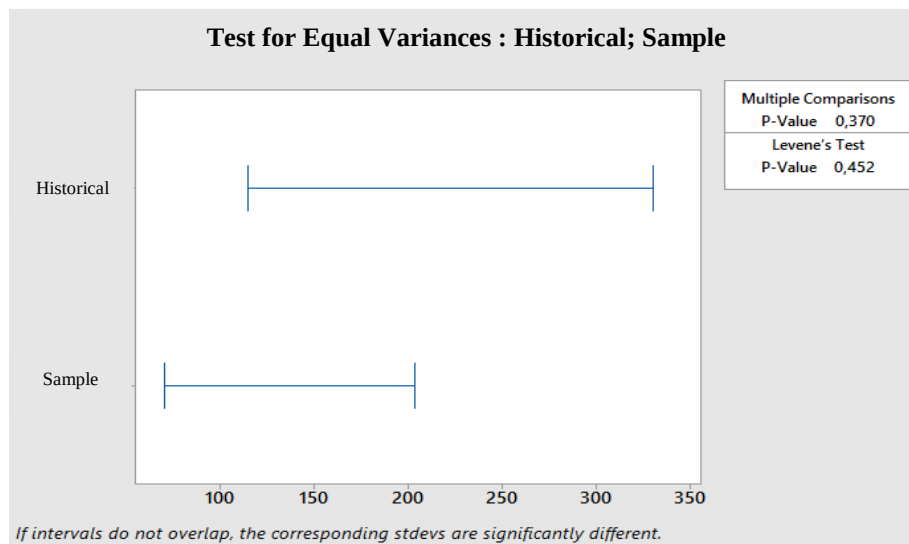
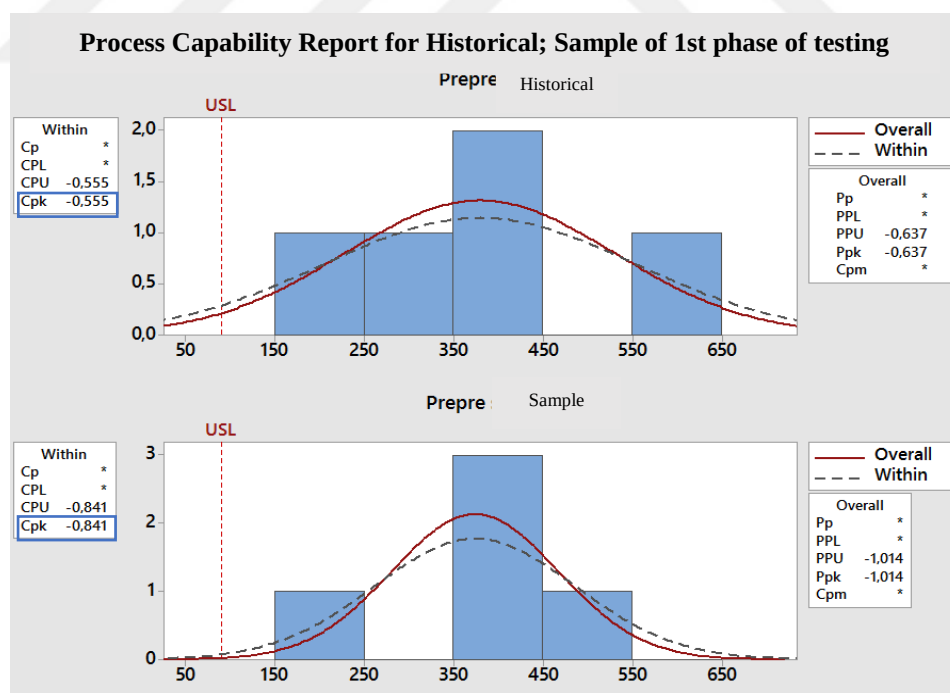


Figure 4.13: Test for equal variances table for 1st phase of historical and sample data.

Figure 4.14 shows the process capability report and Table 4.8 shows the process metrics of 1st phase testing.



Cpk < 0, process is not capable.

Figure 4.14: Process capability of 1st phase of testing.

Table 4.8: Process metrics of 1st phase of testing.

	N	Mean	St Dev	Mean
Historical Data	5	380	152	68
Sample Data	5	374,2	93,4	42

Formulation 4.1 is needed for difference tests.

$$\text{Difference} = \mu (\text{Historical Data}) - \mu (\text{Sample Data}) \quad (4.1)$$

Estimate for difference: 5,6

95 % CI for difference (-189,3; 200,5)

T-Test of difference = 0 (vs $\neq$): T-Value =0,07 P-Value =0,946 DF=6

P>0,05 Fail to Reject Ho, no difference between data - New samples coincide with historical data.

4.8.2 2nd Phase of Testing Data Normality Tests

After the 1st phase of testing datasets, 2nd phase of testing data is recorded and analyzed in this section.

Historically 5 measurements are logged, and then 22 measurements are realized as sample data. Figure 4.15 is summary table. Normality tests are needed to ensure for working with validated data. Normality tests worked on Minitab program.

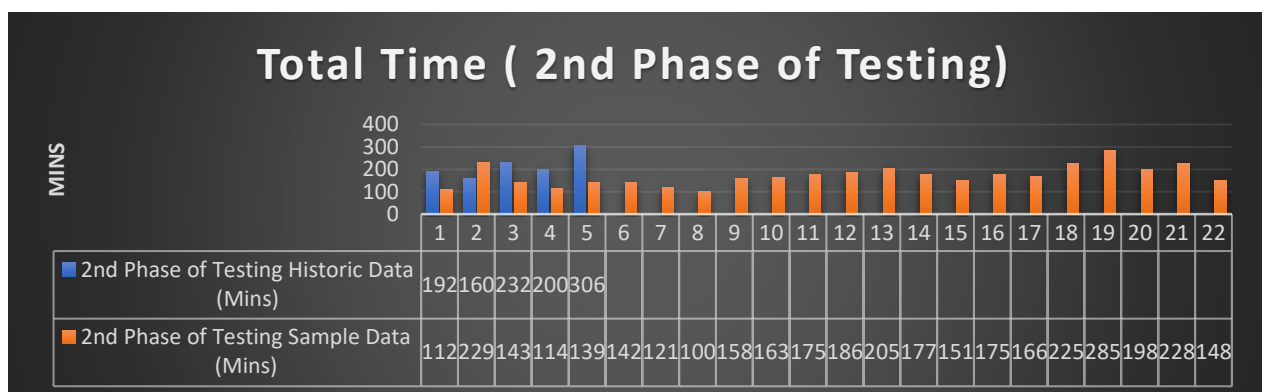


Figure 4.15: Total time of 1st phase of testing.

Figure 4.16 shows the probability plot of 2nd phase testing' historical data. P data is critical in this test. P value is 0,444.

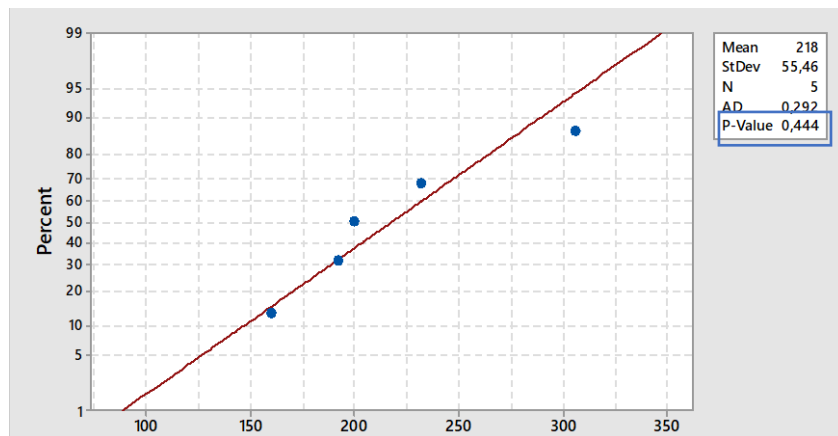


Figure 4.16: Normality test report of 2nd phase testing's historical data.

Figure 4.17 shows the probability plot of 2nd phase testing's sample data. P data is critical in this test. P value is 0,575 and means data set is available.

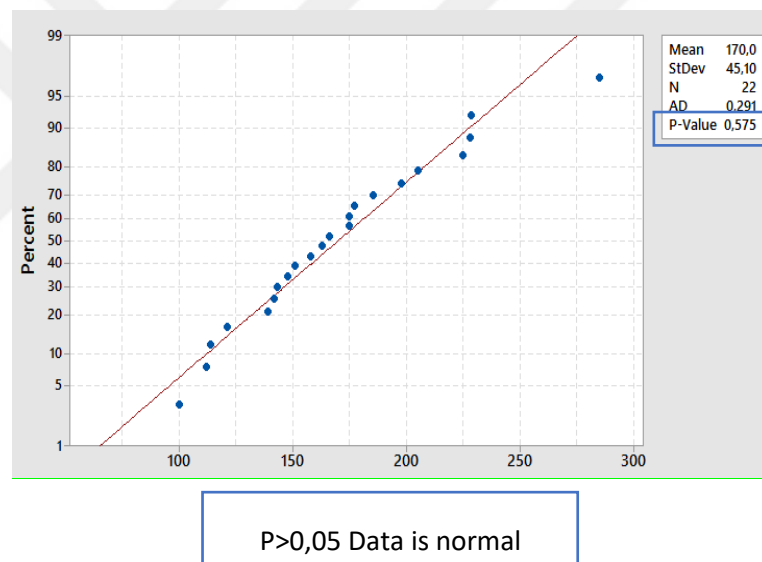


Figure 4.17: Normality test report of 2nd phase testing's sample data.

Figure 4.18 and Figure 4.19 shows the variances, distributions and overlapping. In the boxplot, historical data and sample data have acceptable dataset because median line is centered or nearly centered. In the test for equal variances table have overlapping historical and sample data. Therefore, we can study with these datasets.

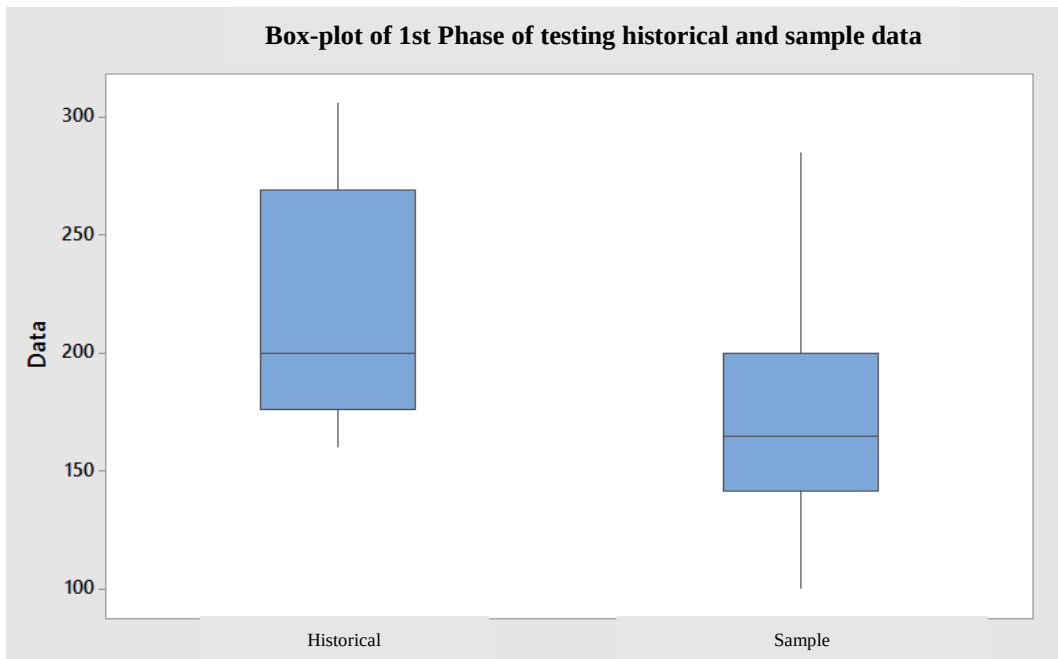


Figure 4.18: Boxplot of 2nd phase of testing historical and sample data.

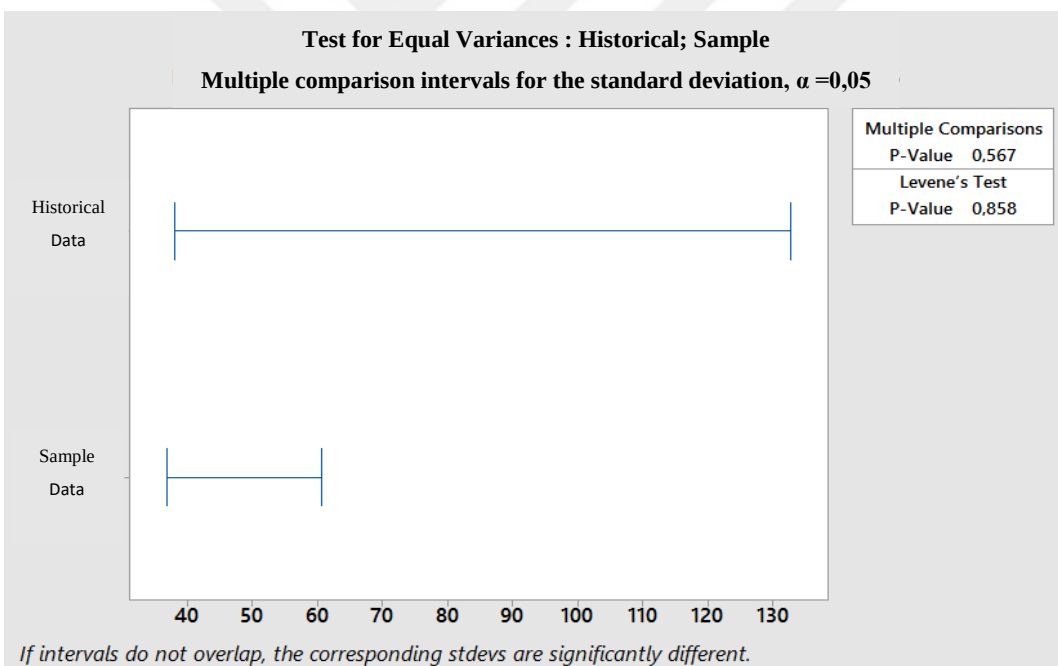
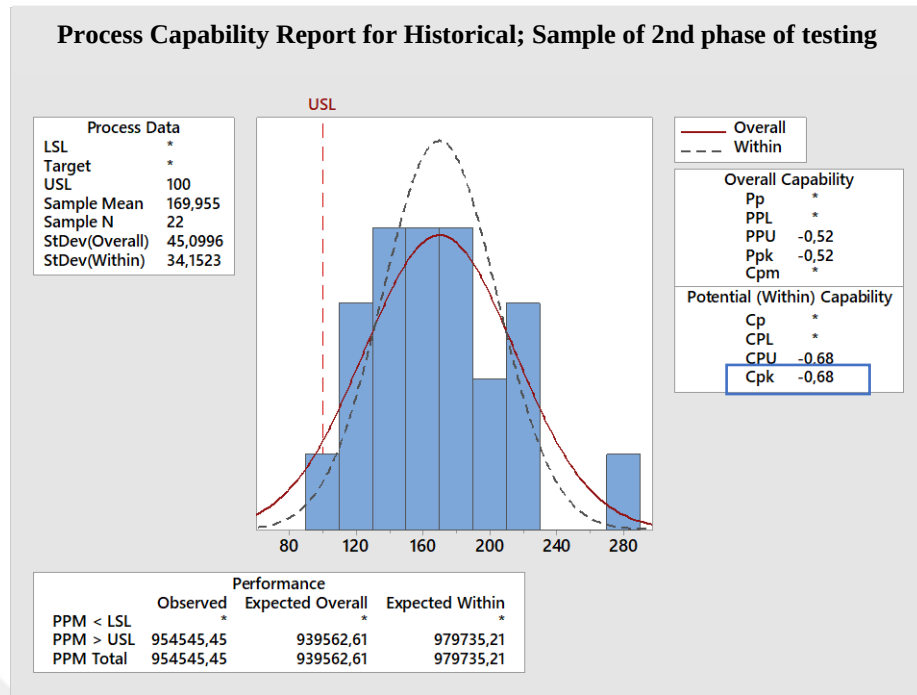


Figure 4.19: Test for equal variances table for 2nd phase of historical and sample data.

Figure 4.20 and Table 4.9 show the process capability and metrics.



Cpk < 0, process is not capable.

Figure 4.20: Process capability of 2nd phase of testing.

Table 4.9: Process metrics of 2nd phase of testing.

	N	Mean	St Dev	Mean
Historical Data	5	218,0	55,5	25
Sample Data	22	170,0	45,1	9,6

Formulation 4.2 is needed for difference tests.

$$\text{Difference} = \mu (\text{Historical Data}) - \mu (\text{Sample Data}) \quad (4.2)$$

Estimate for difference: 48,0

95 % CI for difference (-20,3; 116,4)

T-Test of difference = 0 (vs $\neq$): T-Value =1,81 P-Value =0,131 DF=5

$P > 0,05$ Fail to Reject H_0 , No difference between data - New samples coincide with historical data.

When the detailed measurement data is analyzed, issues which cause time loss and activities which can be optimized are identified. Based on the pareto analysis and

discussion with team members following items that chosen to be improved and to achieve 80% target. Result is 80% improvement.

4.9 Ideal Process Mapping

After the analyze step, process mapping is named ideal process mapping. Ideal process mapping is prepared in Figure 4.21 with improvement actions. Blue: 1st phase of testing, Orange: 2nd phase of testing, Red: Testing.

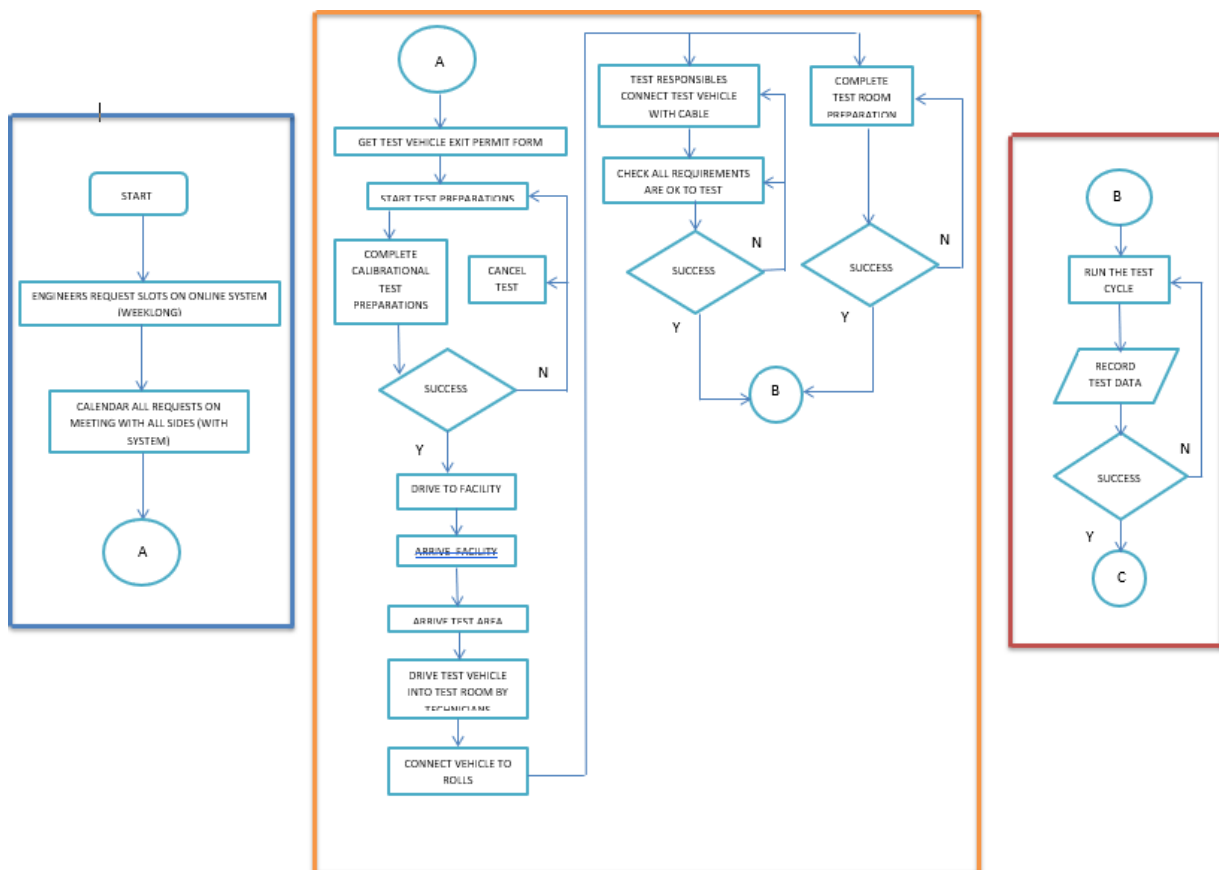


Figure 4.21: Final (ideal) process map.

12 actions were determined for improving steps. These actions' focusing testing phase and explanation is specified. 8 of them are in improvement, 4 of them are in optimization category. Actions are mostly focused on 1st phase of testing. This work based on pareto chart analysis. Action explanations are named in Table 4.10 as A, B, C, D, ..., L, because of information privacy of the company cannot be explained.

Table 4.10: Actions description table.

	Action Type	Action Focus	Action Explanation
1	Improvement	1st Phase of Testing	A
2	Improvement	1st Phase of Testing	B
3	Optimization	1st Phase of Testing	C
4	Improvement	1st Phase of Testing	D
5	Improvement	1st Phase of Testing	E
6	Improvement	1st Phase of Testing	F
7	Optimization	1st Phase of Testing	G
8	Optimization	1st Phase of Testing	H
9	Improvement	2nd Phase of Testing	I
10	Optimization	2nd Phase of Testing	J
11	Improvement	2nd Phase of Testing	K
12	Improvement	1st Phase of Testing	L

After the improve steps, DMAIC control step is succeed. In the control step, actions effects are measured. We measured results on Minitab program.

4.10 Before-After Analysis of 1st Phase Testing

Before- after analysis in the Figure 4.22 of 1st phase testing says that new process has restricted variation and process have more stability comparison with before datasets. If you look at the distribution of the before data set, it is seen how wide the range is intense and the stabilization is low.

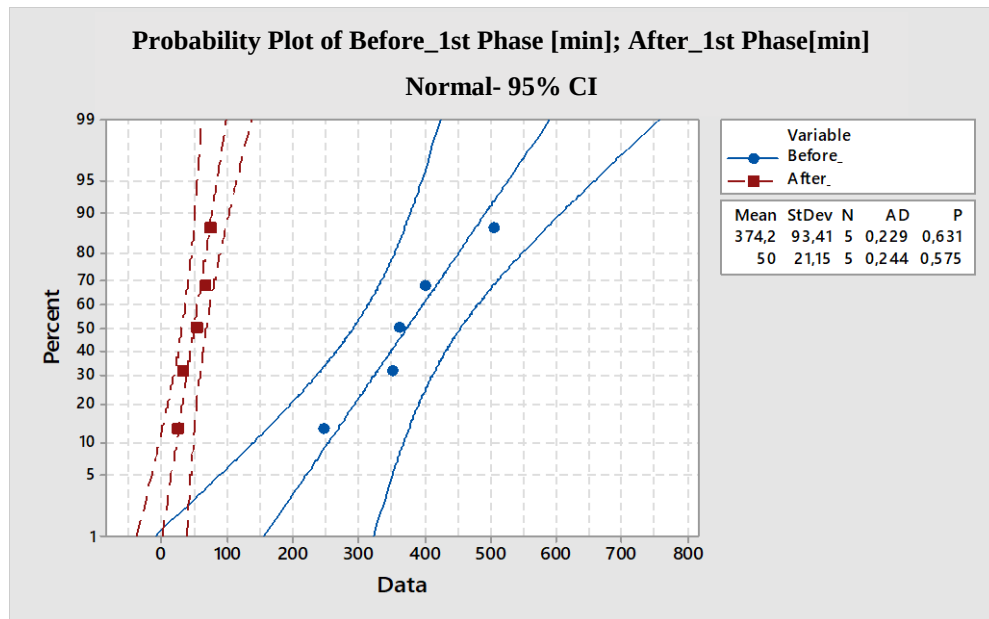


Figure 4.22: Probability plot for before-after analysis (1st phase).

Test for equal variances shows in Figure 4.23 that after the improvement steps, we have same results in narrow range. Before and after dataset intervals do not overlap, so these datasets and processes are significantly different from each other.

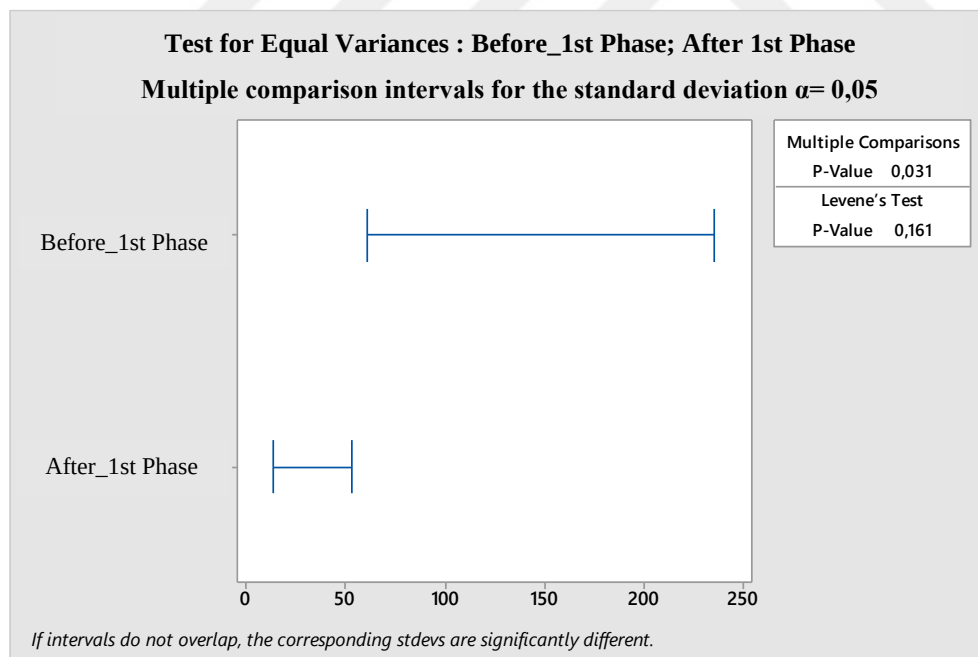


Figure 4.23: Test for equal variances table for before-after analysis (1st phase).

In Figure 4.24, after phase dataset have visible reduction related durations comparison with before processes' datasets. In addition to that, after processes have the median line on centered. It means that, the process has become more stable. Table 4.11 shows the detailed data analysis.

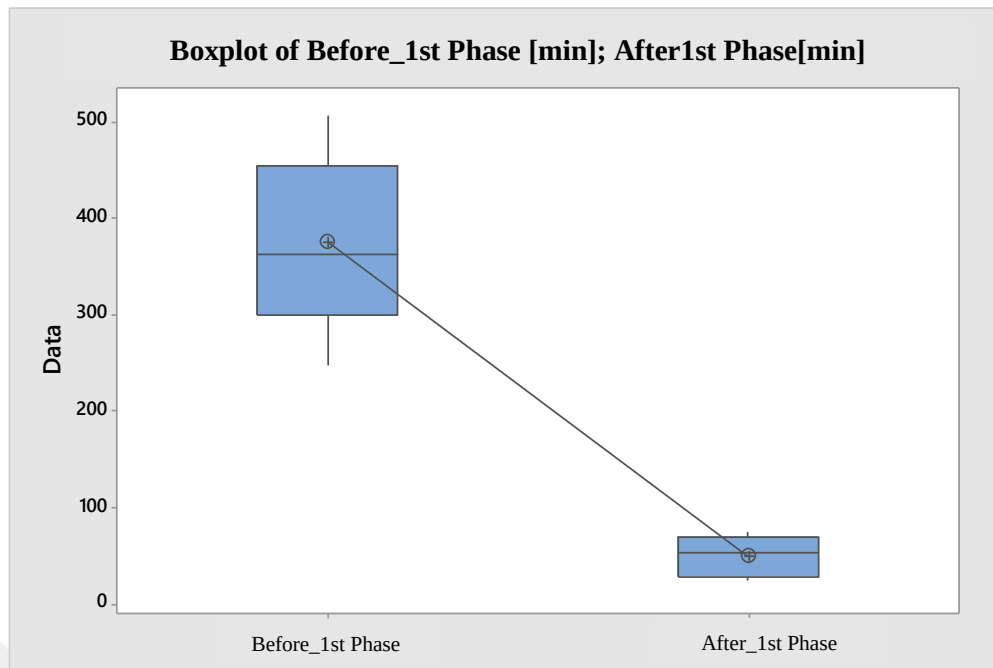


Figure 4.24: Boxplot for before-after analysis (1st phase).

Two Sample T-Test and CI: Before_1st Phase [min]; After_1st Phase [min]

Two-sample T for Before_1st Phase [min] vs After1st Phase[min]

Table 4.11: Before-after analysis data table (1st phase).

	N	Mean	St Dev	Mean
Before_1st Phase [min]	5	374,2	93,4	42
After_1st Phase [min]	5	50,0	21.2	9,5

Formulation 4.3 is needed for difference tests.

$$\text{Difference} = \mu (\text{Before_1st Phase [min]}) - \mu (\text{After_1st Phase [min]}) \quad (4.3)$$

Estimate for difference: 324,2

95 % lower bound for difference: 232,9

T-Test of difference = 0 (vs >): T-Value =7,57 P-Value =0,001 DF=4

P<0.05, Reject Ho, difference exists between before and after improvements.

4.11 Before-After Analysis of 2nd Phase Testing

Before- after analysis of 2nd phase testing in Figure 4.25 says that new process has restricted variation and process have more stability comparison with before datasets. If you look at the distribution of the before data set, it is seen how wide the range is intense and the stabilization is low.

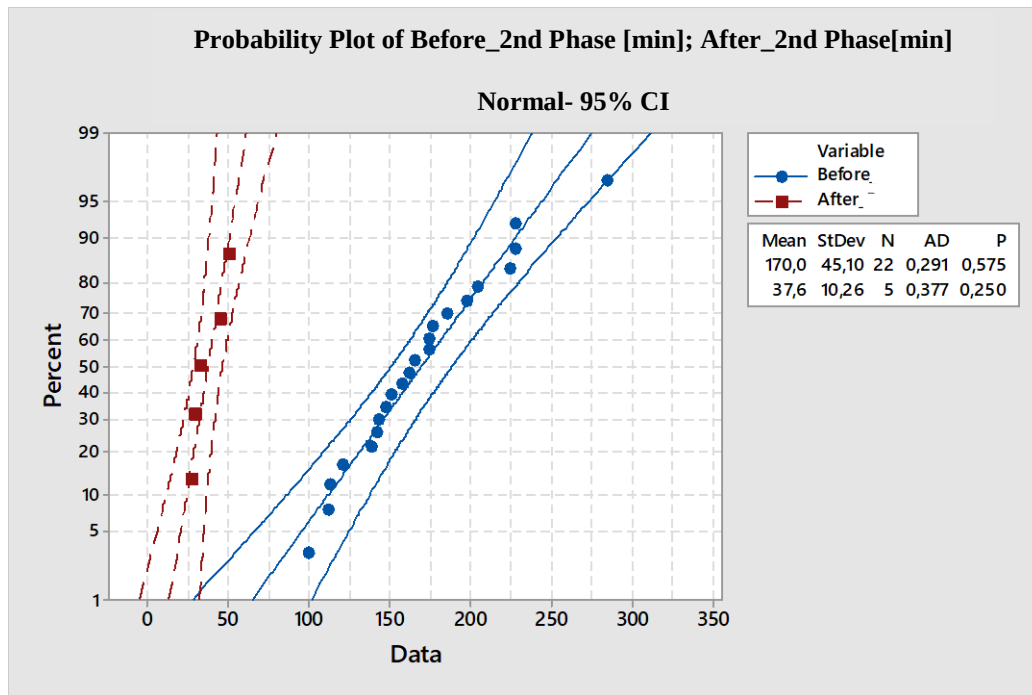


Figure 4.25: Probability plot for before-after analysis (2nd phase).

In Figure 4.26, after phase dataset have visible reduction related durations comparison with before processes' datasets. In addition to that, after processes have the median line on centered. It means the process has become more stable.

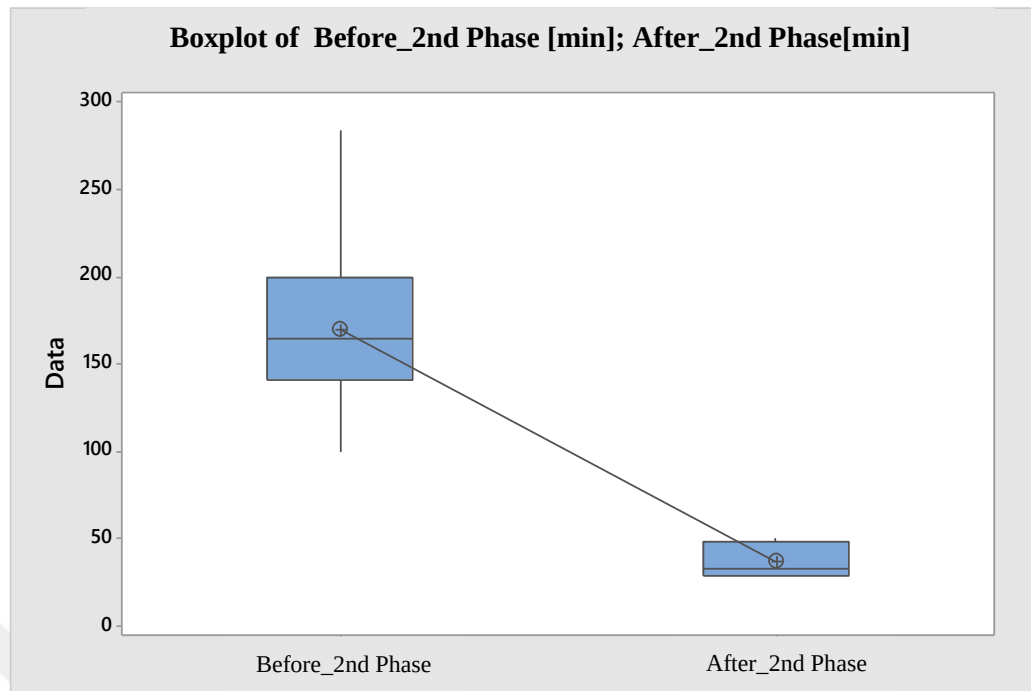


Figure 4.26: Boxplot for before-after analysis (2nd phase).

Test for equal variances table is Figure 4.27 shows that after the improvement steps, we have same results in narrow range. Before and after dataset intervals do not overlap, so these datasets and processes are significantly different from each other. Table 4.12 shows the detailed data analysis.

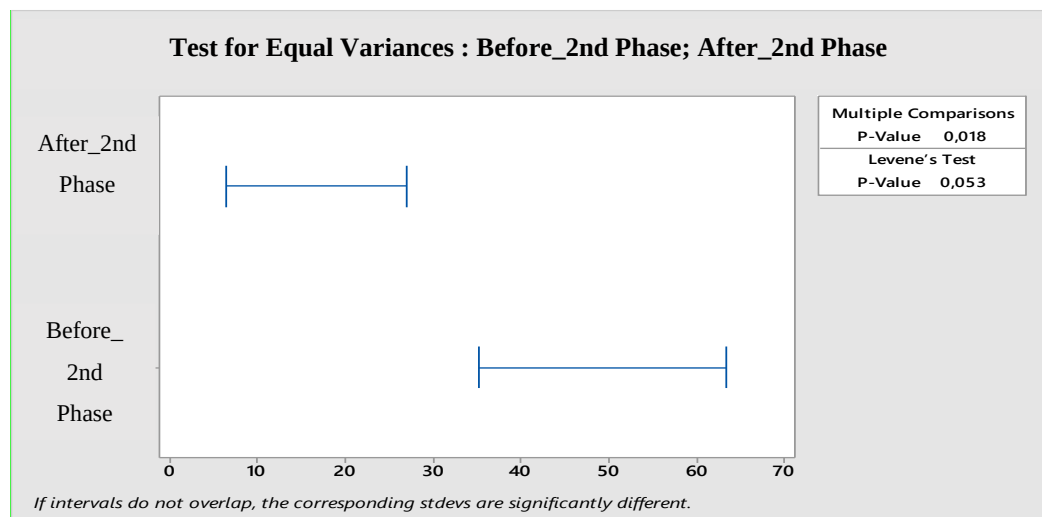


Figure 4.27: Test for equal variances table for before-after analysis (2nd phase).

Two Sample T-Test and CI: Before_2nd Phase [min]; After_2nd Phase [min]

Two-sample T for Before_2nd Phase vs After_2nd Phase

Table 4.12: Before-after analysis data table (2nd phase).

	N	Mean	St Dev	Mean
Before_2nd Phase	22	170,0	45,1	9,6
After_2nd Phase	5	37,6	10,3	4,6

Formulation 4.4 is needed for difference tests.

$$\text{Difference} = \mu (\text{Before_2nd Phase}) - \mu (\text{After_2nd Phase}) \quad (4.4)$$

Estimate for difference: 132,4

95 % lower bound for difference: 114,1

T-Test of difference = 0 (vs >): T-Value =12,42 P-Value =0,000 DF= 24

P<0.05, Reject Ho, difference exists between before and after improvements.

4.12 Summary of Analysis

With-all-of the improvement actions, three tests are done to check what an improvement can be established in the process. First the test results are checked for normality. Afterwards, data is compared to old test results for variance check and check for equal means. Variances are different. Improvement is statically confirmed and reached KPOV metric goals. Summarily, minimizing and eliminating wastes in facility return us as facility cost reduction, engineering man hour reduction, efficiency increasing. Figure 4.28 summarized final report for all phases of testing.

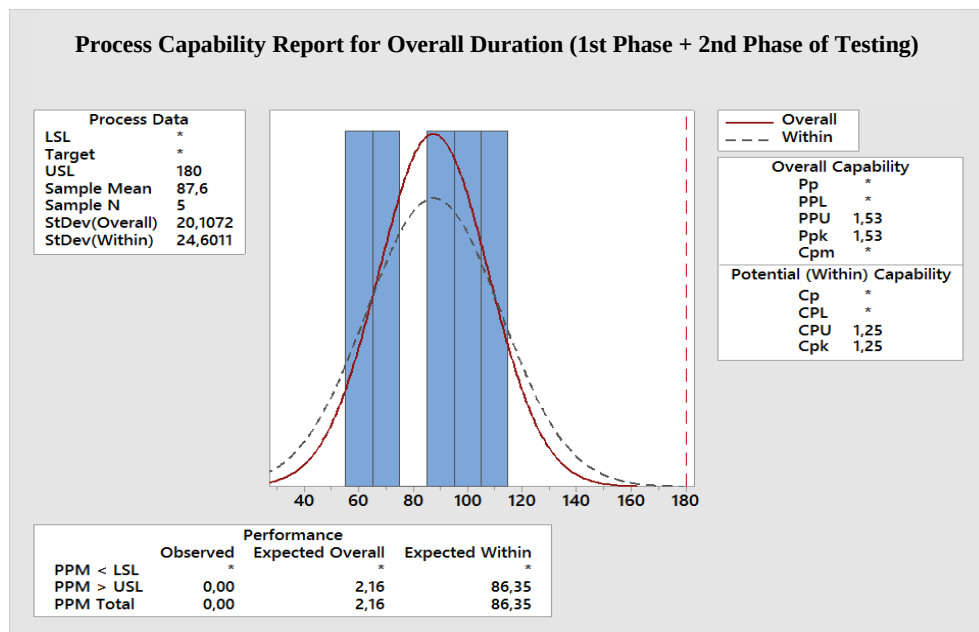


Figure 4.28: Final process capability report.

5. CONCLUSION

"A Process Improvement of Facility Test Efficiency with Six Sigma Methodology in Automotive Industry" paper is the Six Sigma improvement project thesis. Aim of this thesis were eliminating wastes as time, inefficiencies with process improvement on a case study. In the case study in this thesis, case study's observations were made in the emission tests of a company in the automotive sector. These tests are realized in test facility which are different company. The test facility in the case study is completely different companies from the relevant automotive company and the automotive company pays the test facility hourly for the tests. The starting point of the project is the increase in hourly prices paid to the test facility and the number of failed tests. Inefficiencies and wastes are eliminated at the targeted rate with this thesis and six sigma tools as successfully.

Six sigma DMAIC methodology was helped to organize all project steps as define, measure, analysis, improve and control in this work. DMAIC' tools are voice of customer (VOC), CTQ (Critical to quality), SIPOC matrix and diagram, key process output variable (KPOV) metrics, process mapping, fishbone diagram, data collection plan, Pareto analysis and statistical quality control tools are MINITAB, control charts, normality tests, homogeneity of variances, process capability are helped to define, measure, analysis and control for this thesis.

At the end of the project, primary metrics were achieved 1st phase of testing processes time were decreased 05:45:36 to 01:00:00 in average, and 2nd phase of testing duration were decreased as 02:14:52 to 01:30:00 in average. Secondary metric that decreasing waste times on all processes was achieved as a general strategy, vision.

Process capability reports shows the solution of this thesis clearly. First diagram shows the 1st phase of testing dataset before the improvement. USL (Upper specification limit) saved as 01:00:00 and 60 minutes but before improvement data's range exceed the USL excessively. Second diagram shows the 2nd phase of testing dataset before the improvement. In this section, USL located as 100 minutes but almost all measurements were saved over 100 minutes. Both of 1st phase and 2nd phase of testing Cpk value lower than "0" and means processes were not capable.

Figure 5.1 shows the summary of 1st phase and 2nd phase results. USL set as aim of thesis that totally 180 minutes (goal of 1st phase time + goal of 2nd phase time = 60

minutes +120 minutes= 180 minutes). After improvement dataset range in 50 minutes to 110 minutes as you can see on the final diagram. Total situation duration of testing is approximately (1st phase of duration = 05:45:36 =345 minutes + 2nd phase of duration= 02:14:52= 134 minutes) = 479 minutes) decreased to 87,6 minutes (sample mean value). It means the efficiency of this project is 82%.

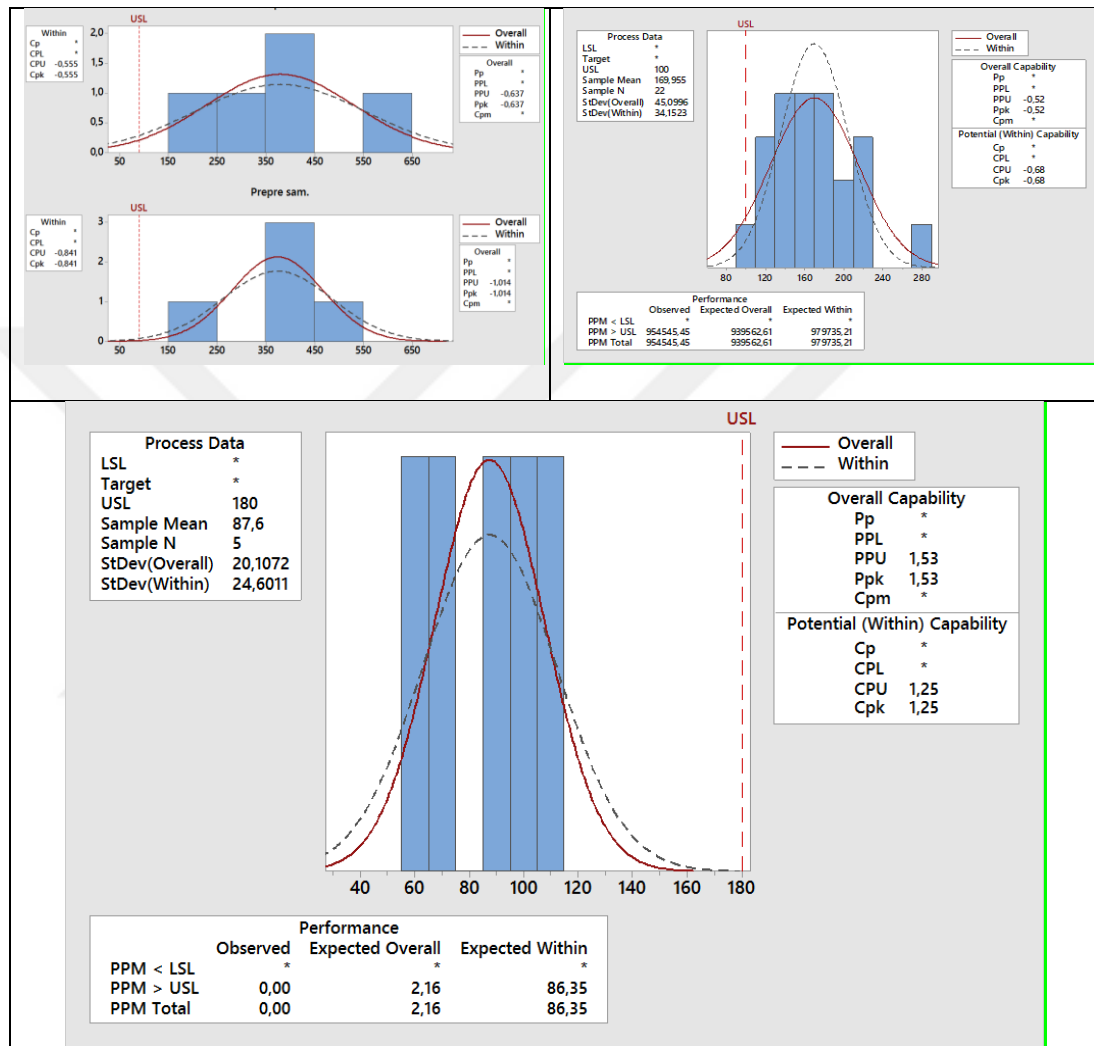


Figure 5.1: Comparing table of process capability report (before-after).

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