NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF MECHANICAL ENGINEERING
INDUSTRIAL MANAGEMENT & OPERATIONAL RESEARCH
LABORATORY OF INDUSTRIAL ENGINEERING

The Application of Lean Six Sigma to update the BOM (Bill of Materials) of the Packaging Process: A Case Study in HALCOR S.A.

by

Sourlatzis Fotios Dimitrios
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Supervisors: Prof. Dr. Tatsiopoulos Ilias
Dr. Papadopoulos Georgios

Dedication

This thesis is devoted to my parents Mr. and Mrs. Fotios, Maria Sourlatzis, and my beloved brother Antonis Sourlatzis. I genuinely value their support and their encouragement to achieve my goals during this challenging period. There were times – especially when my mother was diagnosed with cancer - when I felt discouraged, but thinking of them and how proud they will be of me resulted in my continuing struggle with an end goal to obtain my Diploma Degree in Mechanical Engineering.

Abstract

The present Master thesis was submitted in for the Diploma Degree of Mechanical Engineering at the National Technical University of Athens. This study's scope concerns the research field of industrial management, operational research, and the scientific field of Production Engineer. This study aims to present an improvement project for the case of the Bill of Materials (B.O.M.) of the packaging process by adopting Lean Six Sigma approaches.

The Lean approach's focus in this project is to identify and analyze the related defaults and wastes in the current B.O.M. of the Packaging process. Six Sigma approach plays a vital role to systematically carry out the improvement project applying the D.M.A.I.C. methodology (Define, Measure, Analyze, Improve, and Control). The thesis reports the root causes of the current problematic situation and gives an insight that the right utilization of Lean Six Sigma approaches significantly helped an organization achieve financial savings.

The diploma thesis concludes with the case study, where the D.M.A.I.C. methodology is executed. In this dissertation, only the Define, Measure, Analyze, and Improve phases will be presented. At the end of the Improve phase, the updated Bill of Materials is presented in a MS Excel file and will be further examined through the Control phases.

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List of Abbreviations

CX – Customer Experience

BOM – Bill of Materials

IR4.0 – Industrial Revolution 4.0

IoT – Internet of Things

AI - Artificial intelligence

CI – Continuous Improvement

SQL – Sigma Quality Level

MSA – Measurement System Analysis

LSS – Lean Six Sigma

TPS – Toyota Production System

JIT – Just in Time

WIP – Work in Progress

DPM – Defects per Million

DMADV – Define, Measure, Analyze, Design, Verify

ASQ – American Quality System

JUSE – Japanese Union of Scientists and Engineers

1 Chapter 1 - Introduction

In profit-making organizations like production industries, the ability to meet customer requirements with highly cost-effective operations determined their business's survivability. Leading companies in Customer Experience set a robust foundation in customer satisfaction. "Accomplishing this and realizing how to build upon it to drive positive financial and business outcomes is what separates the leading companies apart from the rest.". (Augie Ray, Gartner).

Although with the fourth Industrial Revolution (IR4.0), the "customer" element is continuously becoming the main subject to be focused. One of the fundamental goals of IR4.0 is to fulfill the complexity of customer needs (e.g., customized products, fast production, perfect quality, reasonable price, etc.) by diverse of high technologies such internet of things (IoT), simulation, artificial intelligence (AI) and predictive process. "The customer is not a king anymore; the customer is a dictator.". (Gerry McGovern)

Despite the statements mentioned above, continuous improvement practice is another critical element that should come concurrently to ensure that business operations stay highly cost-effective and efficient. Lean and Six Sigma are the most approved methods applied to drive the continuous improvement project in many organizations. Using those practices will improve the quality of a process by determining the root cause of defects, developing, and implementing solutions to correct those problems.

1.1 Background of Study

The company specializes in producing a wide variety of copper products with a dynamic presence in the European and global markets. It has been offering innovative and added-value solutions for more than 80 years, meeting synchronous client demands in renewable energy, architecture, engineering, and industrial production. The primary focus is to maintain the production of high quality and added-value products. Consequently, high quality in production processes is achieved through strict controls practiced throughout the production process. The company implements an ISO 9001:2015 Certified Quality Management System and leverages high technologies and expert staff.

Although high quality is achieved, the company has a history of experiencing problems with the B.O.M. of the Packaging process. The company noticed issues concerning B.O.M., which leads to incorrect final costing of the products and a burden on the Product Design Department with additional B.O.M. formatting.

1.2 Problem Statement

Although producing superior quality products is a critical factor for businesses to remain competitive, other parameters contribute to a business's success. Besides superior products, organizations must also be capable of competing regarding price and time limitations. A single case study of the company's current B.O.M. was conducted to investigate potential flaws.

One of the problems at the company is the preliminary costing of different types of packaging. This issue has been caused due to a lack of specific B.O.M. materials and incorrect quantities of materials. Due to the situation described above, the Bill of Materials formatting is performed daily, creating additional workload shared in the Product Design Department.

1.3 General overview of the Research

This dissertation deals with updating the Bill of Materials (BOM) of the packaging process using the Lean Six Sigma methodology.

More specifically, Chapter 1 presents the dissertation's objectives and introduces the importance of Lean Six Sigma as the most popular method that can be applied to drive the continuous improvement project in many organizations.

Chapter 2 presents a comprehensive theoretical overview regarding Lean, Six Sigma, and their combination Lean Six Sigma methodologies. The historical background, as well as the principles and goals of each method, are mentioned to contribute to a better understanding of the reader.

Chapter 3 provides an insight into the study's methodology. In this chapter, a theoretical overview related to research methodology is presented, and the study's approach, design, method, and quality are demonstrated in detail.

In Chapter 4, the D.M.A.I.C. methodology theoretical overview is presented. We analyze every phase (Define, Measure, Analyze, Improve, Control) steps and tools used in Chapter 5.

Chapter 5 includes the Project's execution with the application of the D.M.A.I.C. methodology. In this chapter, we present two of the five core phases (Define, Measure) of the methodology and the updated Bill of Materials is presented.

In Chapter 6, a reflection of the diploma is carried out, and the lessons and conclusions drawn during the course of the research are presented.

Chapter 7 provides a report of the Bibliography used in this thesis.

2 Chapter 2 – Theoretical Overview

"The concept of Continuous Improvement as a strategy and philosophy can be traced back to 2500 BC when people where building pyramids using division of labor, standardization, one-piece flow, and many other fundamentals of Continuous Improvement.". (Burton, 2014). The history of CI has been long, but the primary growth and development happened during several industrial revolutions over the past 200 years.

It started with the first Industrial Revolution, 1780 – 1880, by harnessing water, steam, and standardization. Followed by the second Industrial Revolution, 1880 – 1980, with the birth of scientific management, integrated supply chains, electricity, progressive assembly lines, standard methods, and waste reduction. The third Industrial Revolution, 1980 – 2010, introduced technological improvements that made electronics and computing available for the masses and led to program-based improvements like Lean and Six Sigma. Nowadays, we are through "the Fourth Industrial revolution with mass customization, adaptive systems, and digitalization where everything is connected, and data plays a key role.". (Burton, 2014).

The development of continuous improvement methodologies has happened over time. The following chapters will give a general overview of some of the CI methodologies used – Lean, Six Sigma, and their combination Lean Six Sigma.

2.1 Lean

2.1.1 Historical Background of Lean

Lean thinking methodology, that has passed down from Toyoda Sakichi, founder of the Toyota Motor Company, and master of inventions to his son Toyota Kiichiro, Toyota Motor Company first president and founder of the Japanese passenger car, is the foundation of the Toyota Production System (T.P.S.). "Toyota began its innovative journey in 1949 when Toyota Kiichiro, president of Toyota, demanded that his company had to catch up with the America in three years. Otherwise, the automobile industry of Japan will not survive.". (Ohno, 1988) After World War II, "Japan's economy was shattered, labor productivity was one-ninth that of the United States, and automobile production was failing.". (Hopp & Spearman, 2008).

“In 1950 Taiichi Ohno, a Toyota pant manager, was assigned to understand Ford's production. He visited the U.S. plants and benchmarked them. Besides, he also studied Ford's book "Today and Tomorrow".". (Liker, 2004). He realized that the only way to stand competitive against America would be to shorten the immense productivity gap. This could be achieved only through waste elimination, and aiming at lowering costs. "Unlike the American automotive companies, Toyota could not reduce costs by exploiting economies of scale in giant mass production facilities because the Japanese automobiles' market was too small. Thus, Toyota's managers decided that their manufacturing strategy had to be to produce many models in small numbers.". (Hopp & Spearman, 2008)

By the 1970s, Toyota instituted a host of procedures and systems for implementing Just-in-Time (JIT) production and autonomation, which refers to machines that are both automated. One worker can operate many machines so that they automatically detect problems. They implemented initiatives to reduce set-up times, improve worker training, vendor relations, quality control, and many other aspects from a systems perspective. "While not all the efforts were successful, many where, the overall effect was to raise Toyota from an insignificant company in the automotive market in 1950 to one of the world's largest automobile manufacturers by the 1990s.". (Hopp & Spearman, 2008)

After Toyota rose to one of the biggest automobile manufacturers, managers discovered TPS, and different researchers and practitioners in manufacturing companies tried to understand TPS (lean thinking) and define it. The number of case studies and surveys about Lean implementation has increased over the last 25 years.

2.1.2 Lean Principles and Goals

Lean means doing more with less, using optimized processes to use fewer resources, less inventory, fewer workers, less space. "The center of lean thinking stands the idea of defining value from customers' perspective to design or improve services and products, eliminating all activities and features that do not contribute to the customers' value. As a result, organizations improve waste elimination, time reduction, improved quality, safety, and morale.". (Womack & Jones, 2003).

This is achieved by focusing on five Lean Principles explained by Womack & Jones (2003). It is essential to understand that Lean is not only about waste elimination. These five principles should be viewed as consecutive and explain the core of lean thinking and what the companies need to focus on.

- Specify Value

This principle is defined by examining how a product or service meets the customer's needs. The design of the service or product needs to focus on fulfilling the customer need or in other world businesses have to focus only on value-adding activities and eliminate everything that does not add any value from the customers' perspective. Another factor that value depends on is the time; hence, what customers may consider valuable now may not meet their needs in the coming years.

- Recognize the Value Stream

The value stream is all the activities that contribute to bringing value to a customer. A value stream map lists all activities needed to provide a specific product or offer service. Each step is classified into three categories; those that add value, those that are essential because of regulations but do not generate any value, and those that add no value whatsoever and can be defined as waste. One example of a non-value-adding activity that is usually overlooked is quality inspection. For the end customer, this action does not add any value, the product needs to be made, or services need to be provided already with the customer's desired quality.

- Flow of the Process

This principle means that product, information, or service should move through one value adding-activity to the next one without any delays. Womack and Jones (2003) have an exceptional example "showing how five-sixths of a typical home-building schedule usually consists of waiting for the next set of specialists or reworking.".

- Establish Pull

The next principle associated with Lean thinking suggests that no one from the upstream process should produce or provide anything until the customer downstream asks for it. In this ideal state, there would be no buffers of goods in stock. An excellent example by Womack and Jones

(2003) is that "half of the book's yearly production in the U.S. each year is destroyed without ever finding a reader. A viable solution for that problem would be to print a book when the customer wants to buy it.".

- Process Perfection

Combining the four principles that were previously mentioned, the last principle is achieved. Process perfection is the most crucial principle because it makes employees strive for perfection while offering a product or service closer to customer needs. Womack and Jones (2003) discuss that perhaps "the most crucial motive to achieve perfection is transparency, which is the fact that in a lean environment, everyone can see everything. So, it is easier to discover better ways to create value.".

The following list of wastes is supplemented with the ideas and examples from "The 8 Wastes of Lean" by Nawras Skhmot (2017).

Figure 1: The 8 Wastes of Lean.

Source: Nawras Skhmot, 2017

1. Transportation

Transportation waste includes unnecessary or ineffective movement of parts, information, people, or products. Moreover, unnecessary movement of materials can lead to additional work, exhaustion, and damaged products. Poor processes and layout can cause it. One example could be moving W.I.P. from one place to another for rework purposes.

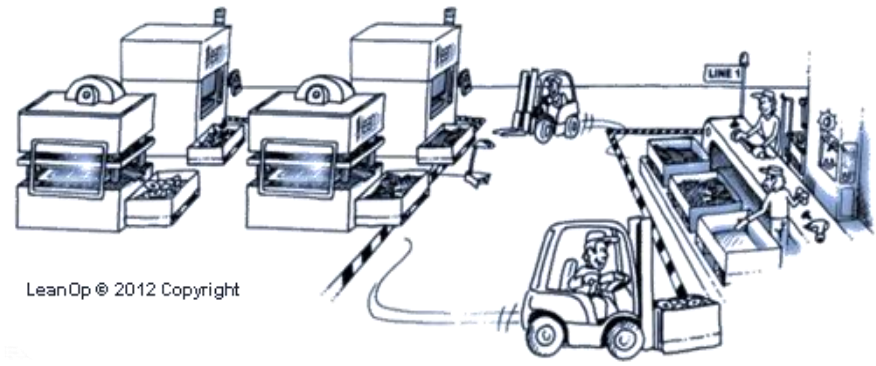


Figure 2: Transportation Waste.

Source: (leanOp)

2. Inventory

Stacks of parts, information, work waiting to be processed, finished products, or information waiting to be transferred. In service, it can be excess inventories that are not needed to provide services to customers. Having more inventory than necessary can lead to problems related to the product's quality and problems being hidden away in the inventory. The money tied under inventories could instead be used to generate value; in finance, it is measured as return on assets.

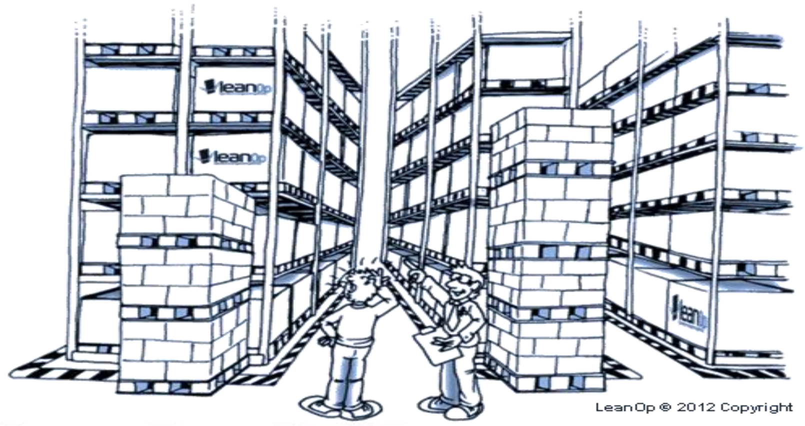


Figure 3: All inventory and WIP.

Source: (leanOp)

3. Motion

This type of waste comprises any undesirable movement of people, equipment, or machinery. As unnecessary time spent in motion, such as for lifting, bending, reaching, and stretching, does not contribute to necessary production tasks, resulting in lower efficiency (Modi & Thakkar, 2014). It can be caused by not optimal placements of tools or in the I.T. sector, making too many clicks to reach for required information, searching for files, and double-entry data, caused by not standardized folder structures. Because both human and machine labor may be affected by unnecessary motion in the long term, tasks that require excessive movement should be redesigned to ensure health and safety levels.

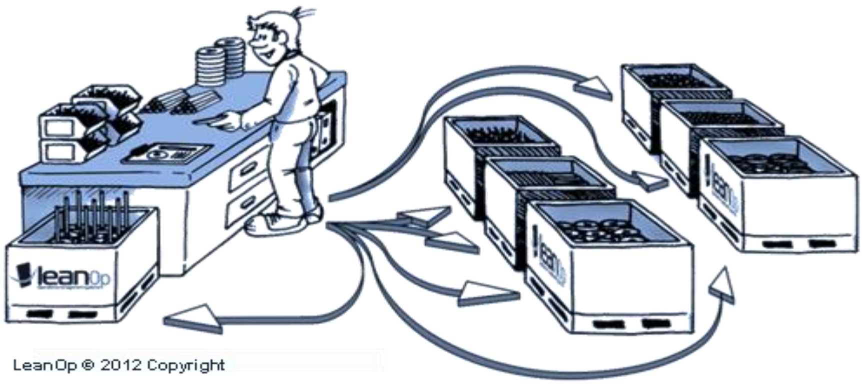


Figure 4: Motion Waste.

Source: (leanOp)

4. Waiting

Waiting is defined as waiting to begin the next step. Time is not used in an efficient way that leads to idle processes. Unbalanced production processes can result in excess inventory and overproduction. Some examples include operators or machines standing idle while waiting for materials to arrive, long or delayed setup times, waiting for approvals before a process can proceed, waiting for responses to emails, and poor departmental communication. Some solutions to eliminate the waste of waiting include redesigning processes to ensure even production flow or single-piece flow, standardizing processes with certain instructions, and developing multi-skilled human resources who can quickly adapt to the demanded changes.

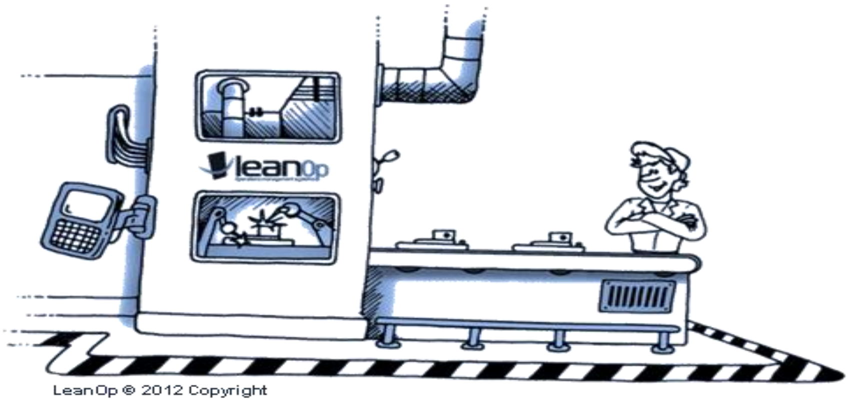


Figure 5: Waste of Waiting.

Source: (leanOp)

5. Over-Processing

This type of waste refers to adding more components, focusing too much on details, doing an over-quality job or product, and giving too much information not required by the customer. Some examples in manufacturing include too many inspection steps during the quality control, additional reworking, and more functionalities in a product than expected. While in service, it may contain more detailed reports than demanded, duplication of paperwork files, unread reports with excessive data, and excessive sign-offs during the processes. Some solutions to counter this type of waste include implementing the five why's method to figuring out why products or services are not provided to the next processes without defects, understand customer requirements before starting work to produce quality, and make only the quantities needed.

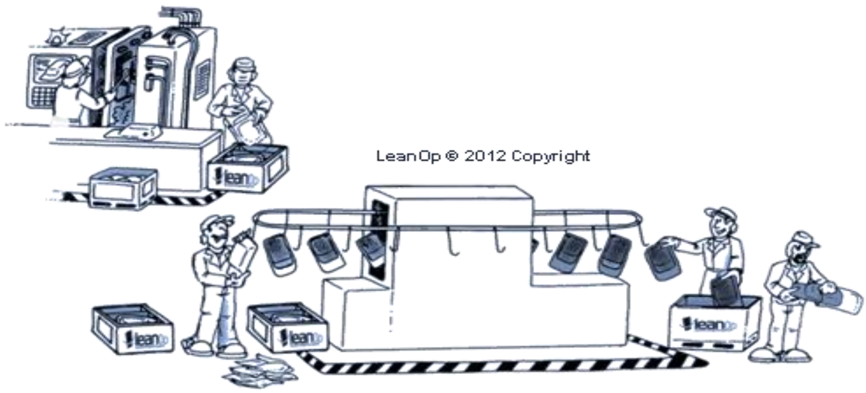


Figure 6: Over-processing waste.

Source: (leanOp)

6. Overproduction

The most serious of the wastes, overproduction, means producing more products or services than the next step requires or more than the customer will purchase. This type of waste can be caused by long or delayed setup times, unreliable processes, inaccurate forecast and demand information, and unstable production schedules. All the causes that were mentioned above lead to a host of problems such as having capital tied up in raw materials and finished products, and the costs associated with their transportation, preventing smooth flow work, and hiding defects inside the W.I.P. Besides, over-producing a product also increases the likelihood that the product or quantities of products produced may spoil or become obsolete, which requires to toss them. In services, it consists of providing more information than required, creating reports that no one reads, and providing a service before the customer is eager to pay for it. Some solutions for this type of waste are reducing setup times, enabling a single-piece flow approach, and applying a pull or "Kanban" system that controls the amount of W.I.P.

Figure 7: Overproduction waste.

Source: (leanOp)

7. Defects

Defects are defined as mistakes in the products, services, and information provided. This most commonly results in rejects, scrapping, or reworking the product. The results are wasteful as they add extra costs to the process without delivering any value to the customer. In addition to the obvious costs, several underlying costs are not always considered, which include increased lead-time, reworking, delivery failures, and potentially lost credibility. In production, the most common instance is to produce something not according to specification. In service, it can be entering incorrect data, adding the wrong recipient in an email, etc.

Figure 8: Defects waste.

Source: (leanOp)

8. Underutilization of intellect

Although it was not mentioned as part of the Toyota Production System, non-utilized talent is a key waste. This waste occurs when the voice of employees who perform the actual work is not considered. It is difficult to improve processes by not taking into consideration the frontline operators' knowledge and expertise. This occurs because operators assigned to complete tasks are the most capable of identifying faults and developing solutions for them. This can be considered as an opposite practice of continuous improvement. Some examples include absent career development and planning, insufficient distribution of tasks, and assigning routine-work to highly qualified employees.

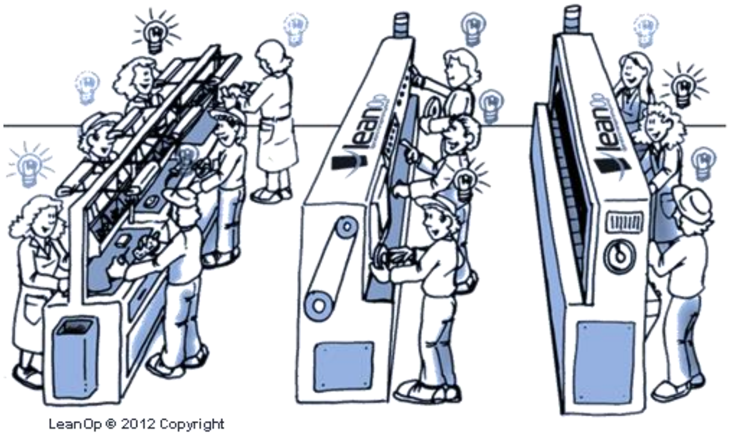


Figure 9: Underutilization of intellect.

Source: (leanOp)

To conclude, "the idea of Lean philosophy has been studied by numerous authors, and they all agree that Lean needs to be viewed as a condition, state of mind, or philosophy rather than a package of improvement tools.". (Bhasin, 2011) (Laureani & Antony, 2011)

2.2 Six Sigma

Six Sigma has become the industry's new strategy to increase profitability and enhance customer satisfaction. Senior company executives averse to other quality management initiatives have embraced Six Sigma as a proven way to decrease costs, grow profit margins, increase market share, and improve customer satisfaction. Six Sigma helps organizations to be high quality, low cost, and lean in everything they do.

"Six Sigma supplements an organization's fundamental business process in a way that ensures the achievement of its long-term vision and objectives.". (Watson, 2004)

"Six Sigma" has taken on several different meanings. It is more of a business strategy than a quality program. According to Gregory H. Watson, Six Sigma can be defined in several ways:

1. "A philosophy of management – where direct linkage among numbers of product defects, wasted operating costs, and level of customer satisfaction with a company's goods and services. It provides a framework that ties together business improvement and quality initiatives and aligns an organization to goals evaluated by their productivity, cost-effectiveness, and quality.". (Watson, 2004)

2. "A process-measurement methodology – where Six Sigma is a way to predict the probability that a process will produce results that meet customer expectations or stated requirements. Less process variation means better process-performance consistency.". (Watson, 2004)

3. "An analysis methodology – Six Sigma is a disciplined, data-driven methodology for decision making using statistical analysis. This methodology combines a step-by-step analytical approach called the D.M.A.I.C. sequence (Define, Measure, Analyze, Improve, Control), to problem-solving, with statistical tools used in a specific

sequence to expose and control sources of variation to optimize process output.". (Watson, 2004)

4. "A business culture – Six Sigma, like in many ways Lean, is a culture that motivates teams to work on a common problem to achieve higher levels of performance effectiveness and productivity at a lower cost. In Six Sigma culture, management by facts, root-cause analysis, and definition of problems according to the source of variation are part of the organization's business language.". (Watson, 2004)

2.2.1 Historical Background of Six Sigma

Walter A. Shewhart successfully connected statistics, engineering, and economics and became acknowledged as the father of modern quality control. The lasting and tangible evidence of that union is the control chart. This simple but highly effective tool represented an initial step toward what Shewhart called "the formulation of a scientific basis for securing economic control." "The control chart is widely used in Six Sigma methodology but was introduced to managers in his monumental work Economic Control of Quality of Manufactured Product, published in 1931.". (Kubiak & Benbow, 2016)

W. Edwards Deming is the most widely known proponent of statistical quality control. In 1942 he suggested a short course in Shewhart's methods to teach the basics of applied statistics to engineers and others. The course's influence on the individuals who later formed the core of the

United States' statistical quality control movement and founded the American Society for Quality (ASQ) is well known. In 1946 and 1948, he went to Japan to study agricultural production and contacted a Japanese statistician Kenichi Koyanagi, one of the founding members of the J.U.S.E. (Japanese Union of Scientists and Engineers), and convinced him of the potential of statistical methods in the rehabilitation of Japanese industry. "In 1950, Deming taught courses regarding statistical methods to Japanese industry and had been characterized as a national folk hero in Japan for being one of the most influential persons in the magnificent rise of Japanese industry after World War II.". (Kubiak & Benbow, 2016)

In the 1970s, when a Japanese firm took over Motorola factory that manufactured television sets in America, they promptly set about making drastic changes in the way the factory was organized. Under Japanese management, the company was soon producing T.V. sets with significantly fewer defects than Motorola's management. "This achievement was made under the same workforce, technology, and designs while lowering the costs - making it clear that the problem was in Motorola's management. On the other hand, Motorola's executives admitted that their quality was low, but it took until nearly the mid-80s before Motorola figured out how to deal with it.". (Pyzdek & Keller, 2010)

Six Sigma's early development of program-based improvement occurred during the years 1985- 1987 at Motorola. Six Sigma was conceived to create significantly better products and processes, which enabled Motorola to compete more effectively with the Japanese. The purpose of Six Sigma is to reduce defects into the parts per million (ppm) range – orders of magnitude better than "typical" quality prevailing at that time. Bob Galvin of Motorola insisted that "product and service quality be improved by 10 percent every two years to achieve this.". This aggressive requirement became the impetus for reducing process variation that soon became known as the Measure, Analyze, Improve, Control (M.A.I.C.) methodology. "This method quickly paid off for Motorola when it became one of the first recipients of the Malcolm Baldridge National Quality Award in 1988.". (Hopp & Spearman, 2008) Companies such as Asea Brown Boveri (ABB), Allied Signal, and General Electric (G.E.) pushed Six Sigma beyond what even Motorola has accomplished.

In particular, Jack Welch of G.E. launched a companywide initiative in 1995 to transform his company from a "great business" into the "greatest company globally." He insisted that every aspect of business be brought under the umbrella of Six Sigma. Furthermore, Six Sigma training would be a requirement for a promotion. "From a financial perspective, G.E.'s annual reports from 1996 – 1999 estimate that savings from Six Sigma to be $1-2 billion per year. In the years following 1995, the value of G.E. stock increased four-fold.". (Hopp & Spearman, 2008)

By the turn of the millennium, Six Sigma had matured into a well-defined methodology known as D.M.A.I.C. At the same time, Companies in fields as diverse as health care, manufacturing, financial services, software development, and home improvement adopted Six Sigma as the basis for their process improvement efforts. "As Six Sigma grew and developed, it became what some practitioners consider to be a complete management system that was successful precisely because of its bottom-line orientation.". (Hopp & Spearman, 2008)

2.2.2 Six Sigma Principles and Goals

"Six Sigma methodology can be related to the Greek letter Sigma (Σ, σ) representing the statistical meaning of sum, or a measure of variability, standard deviation.". (Pande, 2014) (Van Aartsengel, 2013) The relation comes from The Six Sigma movements that started from the need to reduce the variability caused by errors in a production environment. "Understanding how variability degrades performance is key to improving manufacturing and service systems.". (Hopp & Spearman, 2008) Genichy Taguchi has pointed out that "any departure/variation from the nominal or target value for a characteristic represents a loss and is described by his quality loss function.". "A quality loss function is a parabolic approximation of the quality loss that occurs when quality characteristic deviates from the target value. The quality loss function is expressed in monetary units. The cost of deviation from the target increases as a quadric function, the farther the quality characteristic moves from the target. The formula used for quality loss function depends on the type of quality characteristic used.". (Kubiak & Benbow, 2016)

"The quality loss function is described in Figure 10, where m is a target value for a product or service, $m \pm \Delta o$ represents the deviation at which functional failure of the product or service occurs, and in many cases is the specification limit of a product or service, and Δ_o is the cost of countermeasure, which for an average customer is product discarding, replacement or repair.". (Taguchi, Chowdhury, & Wu, 2004)

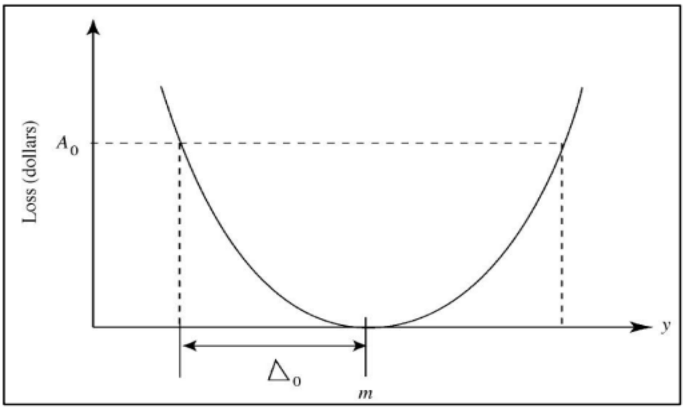


Figure 10: Taguchi's Quality loss function.

Source: Taguchi, Chowdhury, & Wu, 2004

"Six Sigma views all work as a process that can be defined, measured, analyzed, improved, and controlled (D.M.A.I.C.). Processes require inputs and yield outputs; if you control the inputs, you can handle the outputs. This is generally expressed as the y=f(x), outputs are the function of inputs, concept.". (Kubiak & Benbow, 2016) With this concept in mind, control is ultimately achieved when companies can control the variation; more precisely, the fewer variation inputs have, the more predictable the process's outcome. This is where Six Sigma excels, and much focus is set on.

"To control variation, in Six Sigma methodology, common cause and special cause variation are first distinguished. To specify these causes, it is important first to understand the central limit theorem that states - Irrespective of the shape of the population's distribution, the distribution of average values of samples drawn from that population will tend towards a normal distribution as the sample size grows without bound.". (Pyzdek & Keller, 2010) The distinction between common cause and special cause variation is defined through standard deviation and proportion of elements falling within and beyond three standard deviations from the mean illustrated in Figure 11 and Table 1.

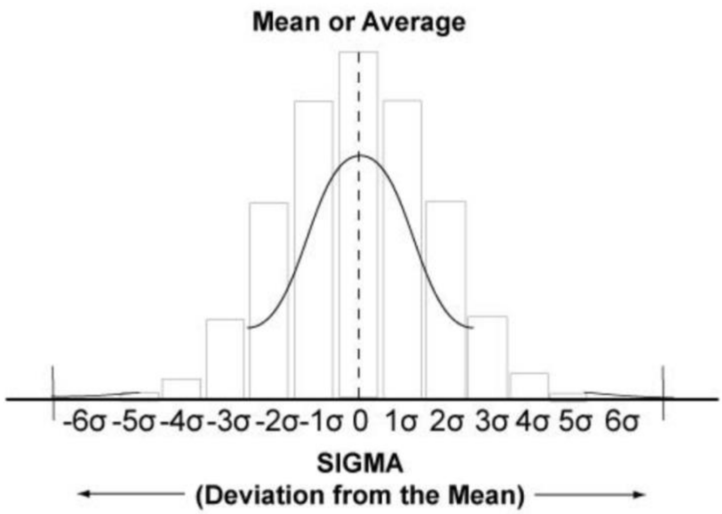


Figure 11: Normal Distribution Curve.

Source: R. Ptacek, T. Sperl, & J. Trewn, 2015

The Normal Distribution is defined by a probability density function f(x) that resembles a bell-shaped curve illustrated in Figure 11 and with the following equation:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{(x-\mu)^2}{2\sigma^2}}$$

Where μ is the process indicating the center of mass of the distribution, and σ is the standard deviation, which indicates the spread.

The standard deviation for the population is found with the following equation:

$$\sigma = \sqrt{\frac{\Sigma(x-\mu)^2}{N}}$$

Process Capability or Sigma Level	Defects (or Errors) Per Million Opportunities (DPMO)	Percent Acceptable
6 σ	3.4	99.99966%
5 σ	233	99.9767%
4 σ	6,210	99.379%
3 σ	66,807	93.32%
2 σ	308,538	69.15%
1 σ	691,462	30.9%

Table 1: Six Sigma Levels.

Source: R. Ptacek, T. Sperl, & J. Trewn, 2015

Shewhart then defines control – "A process will be said to be in control when, through the use of past experience, it is possible to predict, at least within limits, how the process may be expected to vary in the future." "The critical point in this definition is that control is not defined as the complete absence of variation. Control is simply a state where all variation is predictable.". (Pyzdek & Keller, 2010) To understand whether the process is in control, statistical process control (S.P.C.) methods are used. During Shewhart's work on Economic Control of Quality of Manufactured Product, "he created the control chart with three standard deviations around the central tendency as a performance permissible limit of variations. Shewhart's use of 3-sigma limits, as opposed to any other multiple of Sigma, did not stem from any specific mathematical computation. Instead, the choice of 3-sigma limits was seen to be an acceptable economic value, and it was also justified by empirical evidence that it works.". (Van Aartsengel, 2013) Be aware of the above mentioned; it is possible to define that any unknown random cause of variation is within 3- sigma range from the population's central tendency and is defined

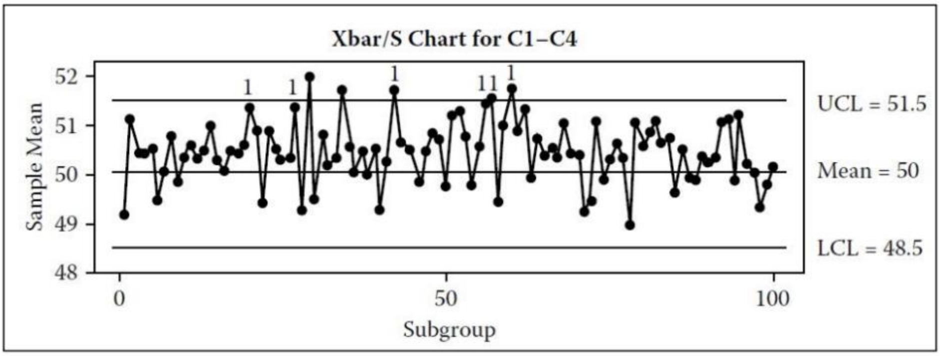


Figure 12: Control Chart illustrating common cause and special cause variation.

Source: Levinson, 2010

as common cause variation. At times, the variation is caused by a source of variation that is not part of the constant system creating systematic patterns or lying beyond the 3-sigma range from the central tendency and is called special cause variation. Common cause and special cause variation are illustrated in Figure 12. All data points above the upper control limit (U.C.L.) and below the lower control limit (L.C.L) are deriving from special cause variation. Everything between U.C.L. and L.C.L. is deriving from common cause variation.

"The basic rule of S.P.C. is a variation from common-cause systems that should be explored "off-line" by looking for long-term process improvements, but special-cause variation should be identified and eliminated.". (Pyzdek & Keller, 2010) Depending on the data set type, distribution, and subgroup size, S.P.C. practitioners can choose between different charts; the decision tree is illustrated in Figure 13, where n is the subgroup size. "Because of this thesis's limitations and extent, all different statistical process control charts will not be described and can be examined independently.". (Pyzdek & Keller, 2010)

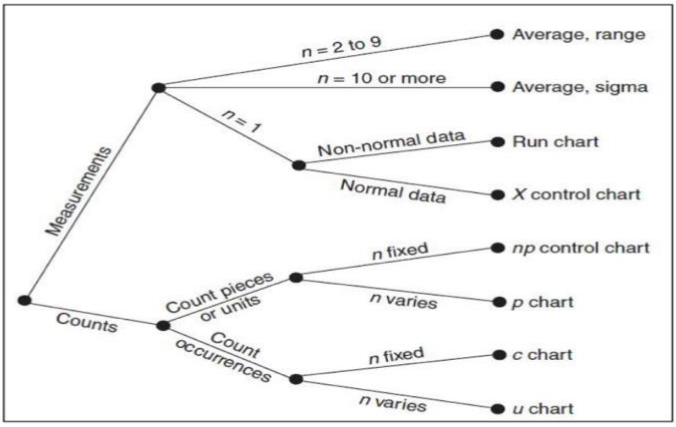


Figure 13: Control chart selection decision tree.

Source: Pyzdek & Keller, 2010

Once special cause variation is understood and eliminated, processes are said to be stable. Practitioners of six Sigma continue their study with the process capability analyses. The process capability analysis refers to a set of statistical methods designed to estimate a manufacturing or service process's capability to meet a set of customer's requirements. The analysis's output is typically an estimate of the percentage of items or service opportunities that conform to those specifications. "If the estimated percentage is large enough, the process is said to be "capable" of producing a satisfactory product or service.". (Polhemus, 2017)

Processes' ability to meet specifications depends on two factors – variation and accuracy. Variation is process capability relative to the specification with, accuracy means that the process mean is nominal. In Six

Sigma, there are four normal states to describe the process against the specification limits. Processes are divided into four categories:

1. In control and meet customers' specifications – low variation and accurate results.

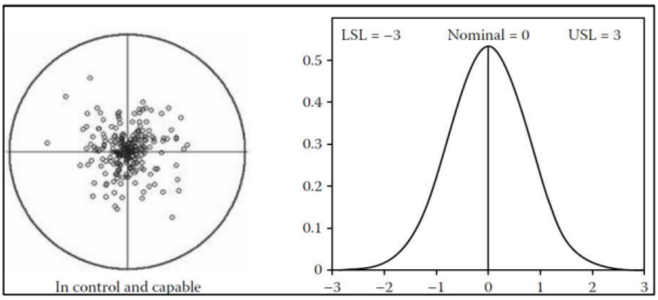


Figure 14: In Control and capable process.

Source: (Levinson, 2010)

2. In control but not capable – high variation but accurate results.

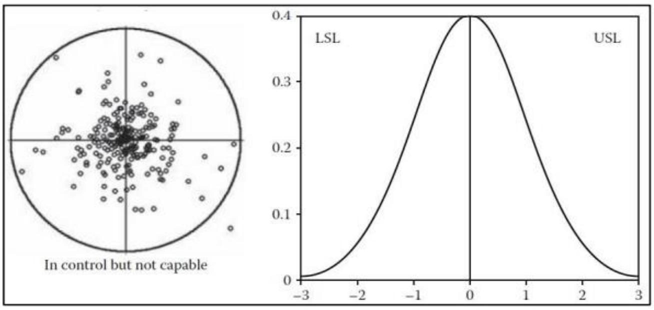


Figure 15: In Control but not capable process.

Source: Levinson, 2010

3. Out of control but capable – a process with low variation but not accurate results.

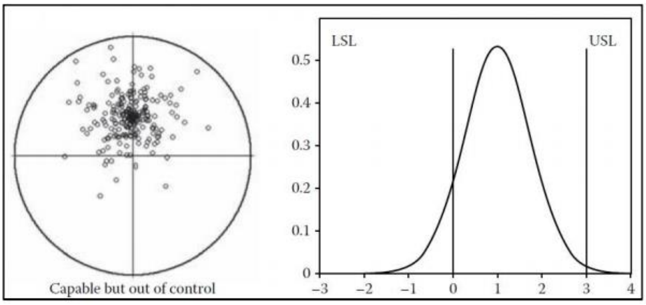


Figure 16: Out of Control and capable process.

Source: Levinson, 2010

4. Out of control and not capable – a process with high variation and not accurate results.

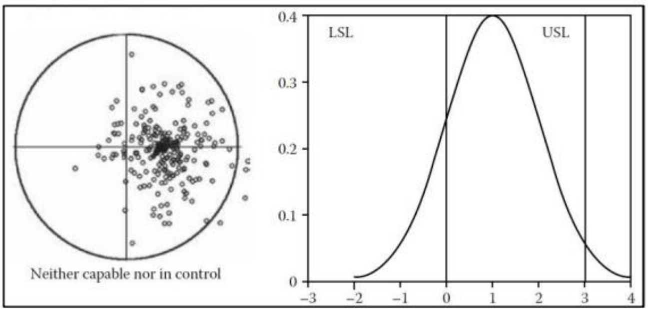


Figure 17:Out of Control and not capable process.

Source: Levinson, 2010

"A frequently used statistic in determining the capability of meeting the customer specifications is the capability index Cpk, which in the case of a normal distribution, divides the distance between the mean and the nearer specification limit by 3σ.". (Polhemus, 2017)

$$C_{pk} = \frac{Z}{3}$$

Where for normal distribution, Z quantifies as the number of standard deviations between the mean and the nearest specification limit. Many organizations strive for Cpk = 1,33, which for the variable data ensures that the distance from the mean of average to the nearer specification limit is at least four standard deviations.". (Polhemus, 2017) Practitioners of Six Sigma also define "Sigma Quality Level" (SQL), which may be attached to any process. By their definition, a process that achieves an SQL of 6 or better produces a product with "world-class quality". "The SQL can be calculated from Z according to SQL = Z + 1,5. The addition of 1,5 to Z comes from the assertion that the mean of most processes is not entirely stable, but tends to vary around its long-term level by approximately ±1,5 standard deviations.". (Polhemus, 2017) Figure 18 shows various quality indices and their corresponding D.P.M. and yield.

Z	C_{pk}	SQL	θ	DPM	$Yield$ (%)
0.0	0	1.5	0.500000	500,000	50.0
0.5	0.167	2.0	0.308536	308,536	69.1
1.0	0.333	2.5	0.158655	158,655	84.1
1.5	0.5	3.0	0.066807	66,807	99.32
2.0	0.667	3.5	0.022750	22,750	99.725
2.5	0.833	4.0	0.006210	6,210	99.379
3.0	1.0	4.5	0.001350	1,350	99.865
3.5	1.167	5.0	0.000233	233	99.977
4.0	1.333	5.5	0.000032	31.7	99.9968
4.5	1.5	6.0	0.000003	3.40	99.9997
5.0	1.67	6.5	0.000000	0.29	99.9999

Figure 18: Relationship between quality indices.

Source: Polhemus, 2017

Once the baseline, or in other words, the capability of the current process is known, measures are taken to reduce the common cause variation and make the process more capable. Because no particular cause variation exists in the process, Six Sigma practitioners use the Pareto principle to quantify the baseline problems that affect the underlying process or service output. "Reasons for failures are often found to conform to the 80/20 principle, which says that 80% of the failures are generally caused by around 20% of the root causes.". (Brook, 2014) "A bar chart, for categorical/contextual data, is widely known as a Pareto chart, where the most frequent results are allocated in order from the left-hand side of the chart. The cumulative frequency is also plotted and shows the reason codes combined from the left of the chart.". (Brook, 2014)

A Pareto chart for defect types is illustrated in Figure 19. "Each defect type is graphed along the x-axis, and the height of each bar is proportional to the number of defects. The graph contains two y-axes. The left y-axis identifies the number of defects and is associated with the bar heights. The right y-axis represents the percentage of defects.". (Kubiak & Benbow, 2016)

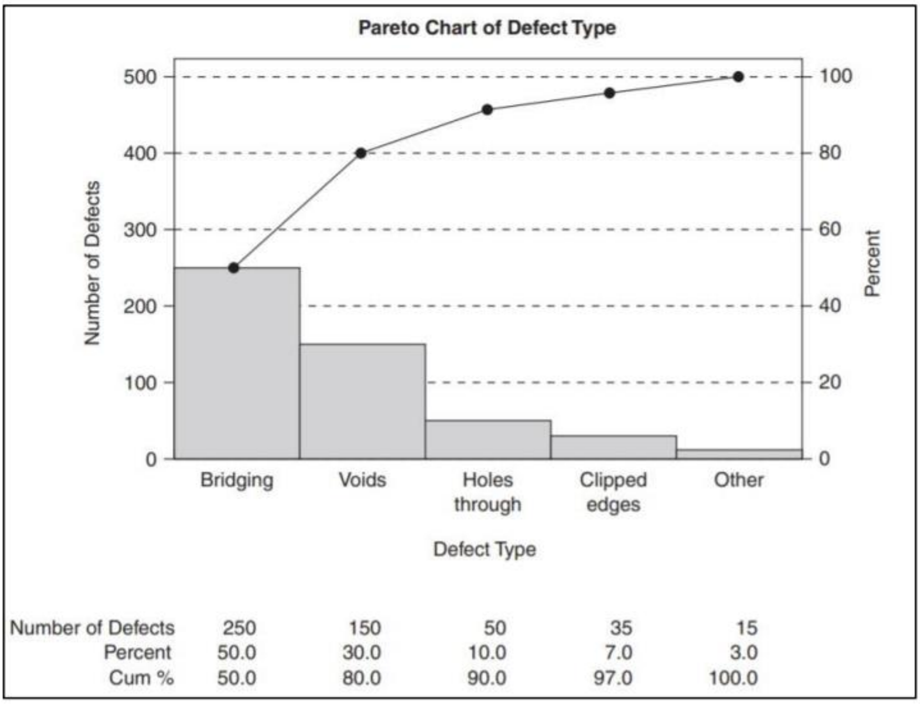


Figure 19: Pareto chart of defect types.

Source: Kubiak & Benbow, 2016

"The cumulative percentage of each defect type is graphed above the bars. The purpose of this chart is to separate the vital few causes from the trivial many.". (Kubiak & Benbow, 2016)

One drawback of Figure 19 is that it assumes all defects have an equal impact. "However, if we quantify the cost of correcting each defect, we can weigh each defect type quantity by the cost of correction. This is quite common practice and can also be applied to other parameters.". (Kubiak & Benbow, 2016)

An example of a quantified Pareto chart is illustrated using Figure 20, which indicates the cost of correcting each defect type. Figure 21 illustrates the end result and "vital few" that should be focused first hand.

Defect type	Cost to correct ($)
Bridging	1.00
Voids	5.00
Holes through	25.00
Clipped edges	100.00
Other	10.00

Figure 20: Cost of correcting each defect type.

Source: (Kubiak & Benbow, 2016)

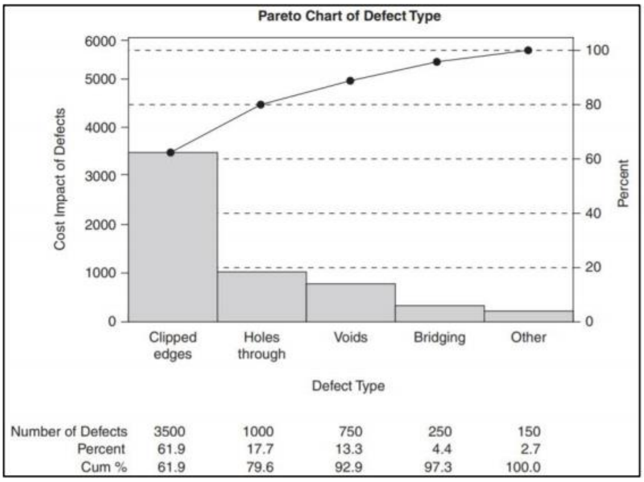


Figure 21: Example of a Pareto chart for defects weighted by the cost to correct.

Source: Kubiak & Benbow, 2016

When the concepts of these ideas are put together - controlling the variation, knowing process capability, focusing on "vital few" root causes, and understanding the Taguchi's quality loss function, one can see that the underlying goal of Six Sigma is to control variation and make processes capable of meeting customer specifications, and through it reduce the cost illustrated by Taguchi's quality loss function.

All the tools mentioned above are part of the D.M.A.I.C. or D.M.A.D.V. improvement cycles used by Six Sigma practitioners. These cycles are similar to the widely known PDCA cycle that was first introduced by Deming and nowadays mostly known from the ISO 9001 standards, which uses it to describe the continuous improvement cycle and requires managers to commit to it. D.M.A.I.C. and D.M.A.D.V. improvement cycles are illustrated in Figure 22.

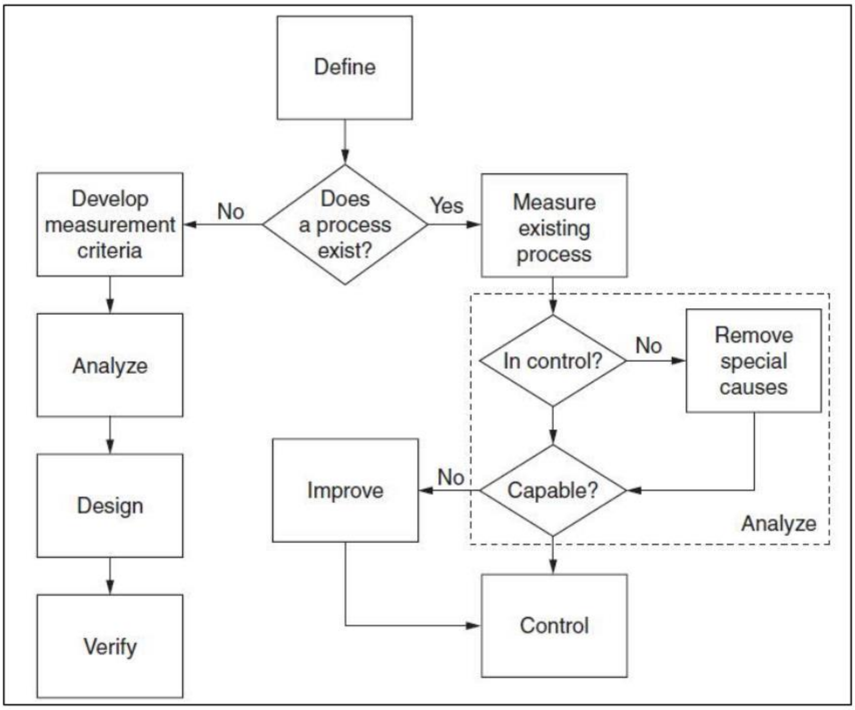


Figure 22:DMAIC and DMADV process cycle.

Source: Pyzdek & Keller, 2010

When cost summaries on quality are made, a question arises – "What are the right costs?" Businesses are seeking a standard against which to compare their actual costs so that they can determine whether there is a need for action or not. One published study (Ittner, 1992) summarizes data on four categories for 72 manufacturing units of 23 companies in 5 industry sectors. Three main conclusions on cost data are drawn: "the total costs are higher for complex industries, failure costs are the largest percentage of the total, and prevention costs are the small percent of the total.". (Juran & Godfrey, 1998)

The study of the distribution of quality costs over significant categories can be further examined using Juran's optimum quality cost model illustrated in Figure 24. The model shows three curves:

1. "The failure costs – these are equal to zero when the product is a 100 % good and rise to infinity when the product is a hundred percent defective.". (Juran & Godfrey, 1998)

2. "The costs of appraisal plus prevention-These costs are zero at a hundred percent defective and arise as perfection is approached.". (Juran & Godfrey, 1998)

3. "The sum of curves 1 and 2: this third curve is marked "total quality cost" and represents the total cost of quality per right production unit.". (Juran & Godfrey, 1998)

Figure 24 suggests that the minimum level of total quality cost occurs when conformance quality is 100 %, i.e., perfection. This model is backed by understanding that prevention and appraisal costs fall after each iteration/usage; thus, perfection is not attained at finite costs. Also, "the impact of quality failures on sales revenue must be quantified. When Taguchi's quality loss function is considered, then the users and producers-cost for not meeting the target value further fuel to the conclusion that the optimum point is perfection.". (Juran & Godfrey, 1998)

"Six Sigma practitioners know that while perfection is obviously the goal for the long run, it does not follow that perfection is the most economic goal for the short run, or for every situation. In the short term, to evaluate whether quality improvement has reached the economic limit, practitioners need to compare the benefits possible from particular projects with costs involved in achieving these benefits. When no justifiable projects can be found, the optimum has been reached.". (Juran & Godfrey, 1998). In the long term, knowledge from previous projects and designs can be reused as best practices to prevent failures from happening. Reusing these best practices is free; increasing prevention affects the need for appraisal thus in time, leading to lesser appraisal and prevention costs, as illustrated in Figure 23, ultimately reaching to perfection as illustrated by Juran's model of optimum quality Figure 24. To conclude, it is worth mentioning that "the prospect is that the trend to a hundred percent conformance will extend to more and

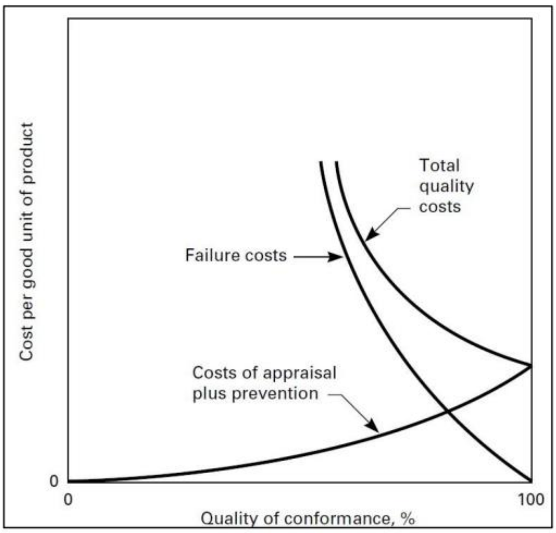


Figure 23:Traditional quality cost curves.

Source: Kubiak & Benbow, 2016

more goods and services of greater and greater complexity.". (Juran & Godfrey, 1998)

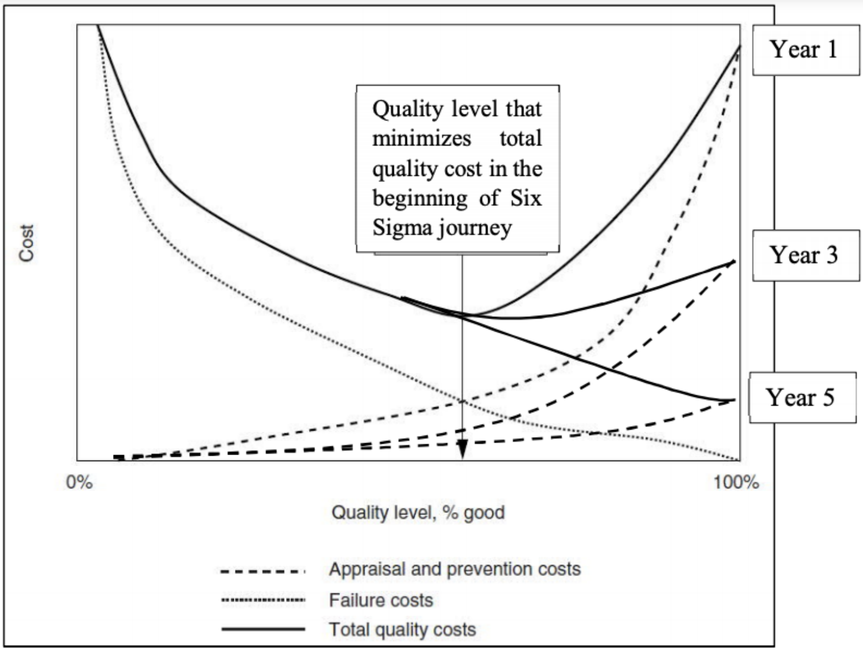


Figure 24: Model of optimum quality costs.

Source: Juran & Godfrey, 1998

To sum it up, Six Sigma focuses on process variation, using several tools and principles to define, analyze, and remove it. By removing the variation from processes, they get more predictable and lower the cost of quality.

Some critical insights by (Pyzdek & Keller, 2010)

1. "Quality is traditionally defined as conformance to internal requirements, a definition that has little to do with Six Sigma. Six Sigma's primary focus is to help an organization make more

money by improving customer value and efficiency.". (Pyzdek & Keller, 2010)

2. "Linking this objective of Six Sigma with quality requires a new definition of quality: the value added by a productive endeavor. This quality may be expressed as a potential quality and actual quality. Potential quality is known as the maximum possible value added per unit of input, and actual quality is the current value-added per unit of input. The main difference between potential and actual quality is waste. Six Sigma focuses on improving quality (reducing waste) by helping organizations produce products and services better, faster, and cheaper.". (Pyzdek & Keller, 2010)

3. "Six Sigma focuses on customer requirements, cycle time reduction, defect prevention, and cost savings. Hence, the benefits from Six Sigma go straight to the bottom line. Unlike mindless cost-cutting programs that diminish value and quality, Six Sigma identifies and eliminates costs that add no value to the customers: waste cost.". (Pyzdek & Keller, 2010)

Some key insights by (Hopp & Spearman, 2008):

1. "A production system cannot be lean if it has low internal quality, i.e., products must be made right the first time. Likewise, a system cannot consistently produce a quality product unless it

is quite lean, i.e., it must have low W.I.P.". (Hopp & Spearman, 2008)

2. "If you do not have time to do it right, when will you find time to do it over?" This aphorism succinctly captures the need for good quality in manufacturing systems.". (Hopp & Spearman, 2008)

3. "Variability must be identified and reduced. Six Sigma aims to identify and reduce variability by determining its root cause and eliminating it. The problem with Six Sigma is that many problems are not always directly related to variability but only indirectly.". (Hopp & Spearman, 2008)

2.3 Lean Six Sigma

"A modern trend in quality management is Lean Six Sigma that integrates Six Sigma and lean systems.". (Russell & Taylor, 2011)

Lean and Six Sigma have the same objective of eliminating waste, to meet the customer's requirements more efficiently. Kubiak and Benbow point out that "the most distinct characteristics between the two approaches are that Lean focuses on waste reduction, and on the contrary, Six Sigma underlines variation reduction. Lean achieves its goals by using less technical tools such as kaizen, workplace organization, and visual controls. In contrast, Six Sigma tends to use statistical data analysis, design of experiments, and hypothesis testing.". (Kubiak & Benbow, 2016)

Over time the demarcation between Six Sigma and Lean has blurred. "Process improvement needs aspects of both approaches to attain positive results. Six Sigma aims to reduce process variation and enhancing process control, whereas Lean drives out waste and promotes work standardization and flow. Lean Six Sigma practitioners should be well versed in both.". (Kubiak & Benbow, 2016)

The implementation began with the Lean approach, applying the 5S (Sort, Set in Order, Shine, Standardize, Sustain), eliminating wastes, and using value stream maps to improve understanding. "When process problems remain, the more technical Six Sigma statistical tools may be applied. Both methodologies have in common that both require strong management support to make them the standard way of doing business.". (Kubiak & Benbow, 2016)

Kubiak and Benbow (2016) give Lean Six Sigma a combined definition:

"Lean Six Sigma is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection. It drives customer satisfaction and bottom-line results by reducing variation, waste, and cycle time while promoting the use of work standardization and flow, thereby creating a competitive advantage. It applies anywhere where variation and waste exist, and every employee should be involved.". (Kubiak & Benbow, 2016)

3 Chapter 3 – Research Methodology

"Research approaches are plans and procedures for research that spread the steps from general assumptions to detailed schemes of data collection, analysis, and interpretation.". (Creswell, 2014) Research may follow the next three approaches: qualitative, quantitative, and other mixed methods. The qualitative research approach is used to obtain information related to understanding underlying reasons, opinions, and motivations. However, a quantitative research approach uses numerical data to quantify the problem. The integration of both qualitative and quantitative research approaches forms the mixed-methods.

3.1 Research Approach

The research approach that was decided to implement this thesis is the mixed-methods. Mixed-methods research is an approach for conducting research that involves collecting, analyzing, and integrating qualitative and quantitative data, and applying distinct designs that may involve theoretical frameworks and philosophical assumptions. Its central premise lies in using qualitative and quantitative approaches combined to provide a more reliable understanding of research problems than either approach alone.

Ary, Jacobs, Razavieh, and Sorenson (2010) divulge the following advantages associated with the mentioned type of approach:

- "Mixed methods research can benefit from the combined strengths of qualitative and quantitative approaches and can make use of the strengths of one method to overcome the weaknesses of another.
- A broader range of research questions can be examined because the researcher is not confined to a single method.
- Mixed methods research can provide more robust evidence for a conclusion through the corroboration of findings.
- The researcher may have insights into what could have been missed with only a single method.
- The combination may produce an understanding of the phenomenon or more complex knowledge to inform theory or practice.". (Ary, Jacobs, Razavieh, & Sorenson, 2010)

Attempting to propose recommendations for the B.O.M. improvement, several aspects needed to be evaluated. Qualitative data had to be obtained through interviews or observing the current processes in the packaging department. In contrast, quantitative data could quickly be collected through measurements, statistical knowledge, and calculations. Utilizing a mixed-methods approach provides a more reliable insight into the problem; therefore, a mixed-methods approach is the most suitable approach for this research.

Research approaches contain three fundamental components: research philosophy, research design, and research methods. Figure 25 presents the interconnection of different worldviews, designs, and research methods.

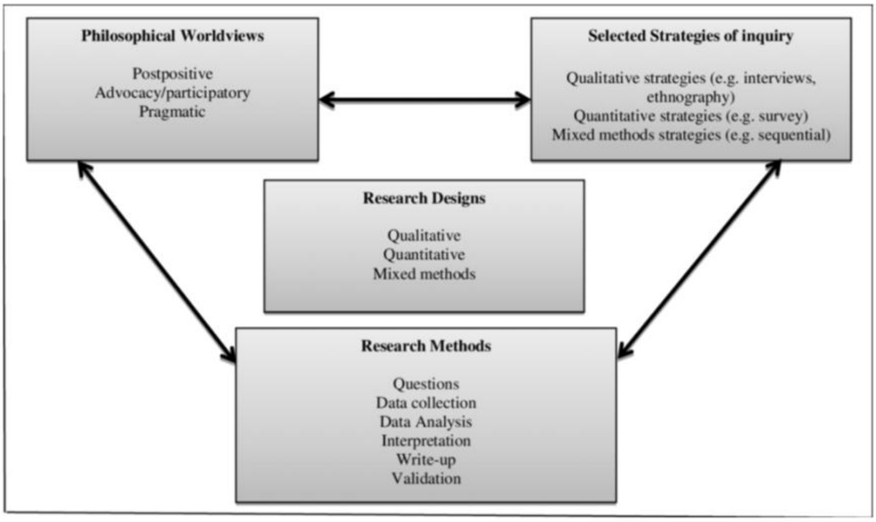


Figure 25: A framework for Research Design – The Interconnection of Worldviews, Strategies of Inquiry, and Research Methods

Source: Creswell, 2009

3.2 Research Philosophical Worldview

A philosophical worldview is "a general philosophical orientation about the world and nature of research that a researcher brings to a study.). Worldviews are also referred to as paradigms and help researchers embrace a research approach.

Four worldviews are distinguished in literature: postpositivism, constructivism, transformative, and pragmatism.". (Creswell, 2014) A brief summary is provided in Table 2 of what each worldview entails.

Postpositivism	Constructivism
• Determination • Reductionism • Empirical observation and measurement • Theory verification	• Understanding • Multiple participant meanings • Social and historical construction • Theory generation
Transformative	**Pragmatism**
• Political • Power and justice oriented • Collaborative • Change-oriented	• Consequences of actions • Problem-centered • Pluralistic • Real-world practice oriented

Table 2: Four Worldviews.

Source: Creswell, 2014

"The postpositivist worldview serves the traditional form of research and holds for true for quantitative research.". (Creswell, 2014) This philosophy admits reported experience, scientific methods, empirical science, and observed human behavior as data. "The problems studied by postpositivist reflect the need to identify and assess the causes that influence outcomes, such as found in experiments.". (Creswell, 2014) The postpositivist worldview "begins with theory, examines data that either supports or refutes the theory, and then makes necessary revisions and conducts additional tests.". (Creswell, 2014)

The constructivist worldview is closely associated with pragmatism and relativism. The constructivist worldview "is to rely as much a possible on the participants' views of the situation being studied.". (Creswell, 2014) In contrast to the postpositivist worldview, the constructivist worldview allows the researcher to develop a theory or pattern of meaning instead of starting with a theory.

The transformative approach is particularly suitable for connecting management consulting and research because it attempts to integrate action and reflection, personal and organizational realities, theory, and practice. "A transformative worldview holds that research inquiry needs to be intertwined with politics and a political change agenda to confront social oppression at whatever level it occurs." (Creswell, 2014). Transformative worldview research "provides a voice for participants, raising their consciousness or advancing an agenda for change to improve their lives.". (Creswell, 2014)

Pragmatism research worldview accepts concepts to be relevant only if they support action. Creswell mentioned, "pragmatism as a worldview arises out of actions, situations, and consequences rather than antecedent conditions, and uses all approaches available to understand the problem.". (Creswell, 2014) Pragmatism's central premise lies in providing solutions and solving problems. The pragmatic worldview is considered to be most appropriate for mixed methods studies, and that provides a rationale why this was chosen to complete this thesis.

"Pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as different forms of data collection and analysis for the mixed methods researcher.". (Creswell, 2014)

3.3 Research Design

Besides finding the most suitable research approach and worldview, researchers are responsible for choosing a research design that falls within the research approach. Research design is defined as "types of inquiry within qualitative, quantitative, and mixed methods approach that provide particular direction for procedures in research design.". (Creswell, 2014) During the research design, the strategies that will be used are also defined. There are four main types of research strategy: case studies, qualitative interviews, quantitative surveys, and action-oriented research. From the strategies mentioned above, the first three are the most common strategies in researches.

A case study is the strategy used to examine the current situation of the Bill of Materials. The definition of a case study is provided below:

1. "A case study is a practical inquiry that investigates a contemporary phenomenon (the "case") in-depth and within a real-world context, especially when the boundaries between phenomenon and context may not be evident." (Yin, 2014)
2. "A case study inquiry copes with the technically characteristic situation in which there will be more variables of interest than data points. As one result relies on many sources of evidence, with data necessitating to converge in a certain fashion, and as another result, benefits from the prior development of theoretical propositions to guide data collection and analysis." (Yin, 2014).

The first portion of the definition provides information regarding the scope of the case study, and the second provides information regarding the characteristics of a case study. "Case" refers to the study's general purpose. "Common cases embrace individuals, organizations, programs, processes, institutions, and events.". (Yin, 2014). "Case study research is a preferred strategy on inquiry when the questions associated with the research are "why" and "how.". (Yin, 2014). "The more your questions attempt to explain some current circumstance, the more that case study research will be relevant.". (Yin, 2014)

Strategy	Form of research question	Requires control over behavioural events?	Focuses on contemporary events?
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Unobtrusive measures	Who, what, where, how many, how much	No	Yes/No
Case study	How, why	No	Yes

Figure 26:Selection Criteria for Different Research Strategies.

Source: D. Gray, 2014

3.3.1 Case Study Type

The case study types are divided into four major categories: single case and multiple case studies, which can be holistic or embedded. A single embedded case study appraises one case, and there are several units of analysis. A single holistic case study appraises one case, and there is one unit of analysis. A multiple embedded case study appraises multiple cases, and there are several units of analysis. A multiple holistic case study appraises multiple cases, and there is one unit of analysis. Figure 27 illustrates each of the case study types.

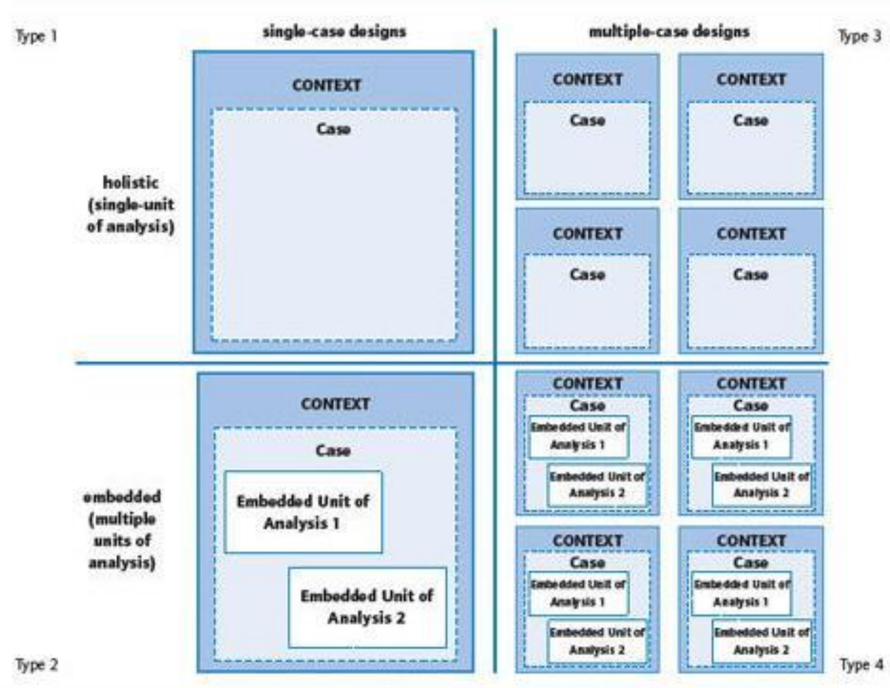


Figure 27: Case Study Designs.

Source: R.Yin, 2014

A single holistic case study design was decided to implement in order to carry out this research. "A single case study can be used to confirm, deny, or further investigate a theoretical proposition. This type of study can also help redefine investigations within the study.". (Yin, 2014) Applying Lean Six Sigma's D.M.A.I.C. methodology to discover faults in processes and make recommendations for improvements will prove that the D.MA.I.C. methodology can be utilized to improve processes and remove wastes. The rationale for a single holistic case study design is that there is only one unit of analysis (the company's Bill of Materials) to complete this study, and the research involves a single company's B.O.M.

3.3.2 Case Study Reasoning

Another essential to determine parameter is whether the study will follow an inductive or deductive reasoning approach. "Inductive approach, plans are made for data collection, after which the data are analyzed to see if any patterns arise that suggest relationships between variables.". (Gray, 2014). "Inductive approach is also implemented when cases do not start from a theoretical position, and observations from inductive approaches can construct generalizations.". (Gray, 2014) "The deductive approach moves toward hypothesis testing, after which the principle is confirmed, refuted, or modified.". (Gray, 2014) "A deductive approach is used when the case study begins with a theoretical position and is confirmatory in nature. When using a deductive approach, theoretical positions are tested through empirical observation and experimentations.". (Gray, 2014) The research begins applying Lean Six Sigma's D.M.A.I.C. practices, examine the current Bill of Materials of the packaging process, and compares the study's results (new B.O.M.) with the B.O.M. that already exists; therefore, this thesis employs an inductive reasoning approach.

3.3.3 Case Study Design

Every case study has an associated research design. Yin (2014) mentioned, "A research design is a logic that links the data to be collected (and the relative conclusions) to the primary question of the study.". (Yin, 2014) "The case study's design serves a blueprint for the research and provides information about what questions should be studied, what data is relevant, what data should be collected, and how results should be analyzed.". (Yin, 2014) The fundamental components of a case study are:

1. Theoretical propositions associated with the case study.

   - The application of Lean Six Sigma D.M.A.I.C. methodology, to make recommendations for process improvement

2. Questions associated with the case study.
3. Unit(s) of analysis.

   - The Bill of Materials of the Packaging process.

4. Logic that links that data to the propositions.

   - Pattern matching was used to link that data to the propositions.

5. Criteria for interpreting the case study's findings.

   - Through statistical analysis case study's findings were interpreted.

3.3.4 Case Study Concerns

According to Yin (2014) the five traditional concerns about using a case study as a strategy of inquiry include:

- Lack of scientific rigor?
- Confusion with teaching cases?
- Generalizing from case studies?
- Unmanageable level of effort?
- Comparative advantage?

"The first concern is known as the most significant concern and was derived as a result of researchers not following systematic procedures or not having proper evidence to support findings and conclusions.". (Yin, 2014) This problem is resolved by the use of methodological text as a model for designing the case study.

"The second concern relates to case study research being confused with the type of case study used in teaching. Unlike case studies used in teaching, the alteration of case study research is forbidden.". (Yin, 2014).

The third issue includes limitations to generalize from research findings. "In fact, generalizations in science are rarely based on single examinations; they are usually derived from a reoccurring set of experiments that have replicated the same event under different conditions"." (Yin, 2014) This issue is mentioned as the findings of this case study can be used to generalize hypotheses related to Lean Six Sigma D.M.A.I.C. techniques to optimize processes.

The fourth issue is pointing the lack of time to complete the analysis or examine important documents. "This concern incorrectly confuses case study research with a specific method of data collection such as ethnography or participant-observation.". (Yin, 2014)

The ambiguous comparative advantage is the final concern of using a case study as an investigation strategy. "This issue especially emerged during the first decade of the 21st century, which favored randomized controlled trials (RCTs) or "true experiments," especially in education-related topics.". (Yin, 2014)

3.4 Research Method

"Research methods are specific forms of data collection, analysis, and interpretation used to complete a study.". (Creswell, 2014) In the next sections, more tools and practices will be presented that help to the research's execution.

3.4.1 Data Collection

The fundamental need of data collection is to gather observations or measurements. Although methods and priorities may vary from field to field, the general data collection approach remain relatively the same. Before you start the data collection, it is critical to consider:

- The purpose of the research.
- The tools and methods you will use to collect, store and process the data.
- The type of data you are trying to gather.

Before the different types of data collection are addressed, it should be mentioned that the collection of data itself falls into two distinct categories: primary data collection and secondary data collection.

Primary data collection introduces gathering of raw data collected at the source. The original data are collected by a researcher for a specific research purpose. Sources of primary data collection include surveys, interviews, and observations.

On the other hand, secondary data collection is defined as the collection of second-hand data gathered by an individual who is not the original source. It is the process of data collection that already exists, be it books , journals and/or web portals that have already been published. In terms of convenience, collection is much less expensive and faster.

Preference between primary data collection and secondary data collection depends on research's design, scope and location, as well as its goals and objectives. This thesis combines both primary and secondary data sources, in order to better meet the project's needs. Yin (2014) claims, "Case study evidence may come from six sources: documents, interviews, archival records, physical artifacts, direct observations, and participant-observations.". (Yin, 2014)

- Documents

"Documents include letters, emails, agendas, memoranda, announcements and minutes of meetings, proposals, progress reports, formal studies or evaluations, news clippings, articles, etc.". (Yin, 2014) "For case study research, the most crucial use of documents is to corroborate and augment evidence from other sources.". (Yin, 2014)

- Archival Records

Archival records include access manuscripts, documents, or records from libraries, depositories, or the internet. "The value of these archival records will vary from case study to case study. In some studies, the records can be so important that they become the object of extensive retrieval and quantitative analysis. In other studies, they may be of minor relevance.". (Yin, 2014)

- Interviews

In a case study, a series of interviews may take place to gain an in-depth understanding of perceptions or opinions on a topic. Interviews may be distinguished into three basic categories: prolonged interviews, shorter interviews, and survey interviews. “Prolonged interviews take place for two or more hours and can occur in either a single sitting or multiple sittings.". (Yin, 2014) "Prolonged interviews allow the researcher to gain insight into the interviewee's interpretations and beliefs about people, events or their insights, and meanings related to certain circumstances.". (Yin, 2014).

"Shorter interviews do not last more than an hour and occur in one sitting.". (Yin, 2014) "Survey interviews are administered through structured questionnaires and yield quantitative data as a part of the case study testimony.". (Yin, 2014) Since most case studies are about interpersonal experiences, interviews are a necessary source of case study data. "Well-informed interviewees can give insights into such affairs or actions, and can also provide shortcuts to prior history or situations, helping identify other relevant evidence sources.". (Yin, 2014).

- Direct Observations

Since case studies, analyze circumstances in real-world environments, direct observations act as a basis of case study data. "Observations of meetings, factory work, and classrooms are examples of direct observations used for formal data collection.". (Yin, 2014) "Observations during fieldwork, such as a collection of other sources of evidence (i.e., interviews), is an example of direct observation used for casual data collection.". (Yin, 2014) In understanding any field of research, direct observations play a key role. "Observational evidence is often useful in providing additional information about the topic being studied.". (Yin , 2014)

- Participant- Observation

Participant-observation refers to a type of observation that enables the observer to play an active role in the examined situation or behavior. In small groups as well as big firms, this source of proof may be used. "Participant-observation is useful because of its ability to provide unusual opportunities for data collection.". (Yin, 2014). "The unusual opportunities for data collection are identified as follows:

- Ability to gain access to events or groups that would not usually be accessible.
- Ability to perceive reality from the viewpoint of someone inside the case.
- Ability to manipulate minor events.". (Yin, 2014)

- Physical Artifacts

"Physical artifacts, also known as cultural artifacts, are not typically relevant in most case studies but can be an asset to the entire case when deemed relevant". (Yin, 2014) Physical or cultural artifacts provide valuable information about the culture of the individual who created the artifact as well as the individuals who used the artifact. Examples of physical artifacts include technological devices, tools, and instruments. "Such artifacts may be collected or observed as part of a case study and have been used extensively in anthropological research". (Yin, 2014)

Either one of the cited sources has its own strengths and weaknesses. A summary of the six sources of evidence commonly used for case studies and the strengths and weaknesses associated with each source are provided in Table 3.

SOURCE OF EVIDENCE	Strengths	Weaknesses
Documentation	• Stable–can be reviewed repeatedly • Unobtrusive–not created as a result of the case study • Specific–can contain the exact names, references, and details of an event • Broad–can cover a long span of time, many events, and many settings	• Retrievability–can be difficult to find • Biased selectivity, if collection is incomplete • Reporting bias–reflects (unknown) bias of any given document's author • Access–may be deliberately withheld
Archival records	• *[Same as those for documentation]* • Precise and usually quantitative	• *[Same as those for documentation]* • Accessibility due to privacy reasons
Interviews	• Targeted–focuses directly on case study topics • Insightful–provides explanations as well as personal views (e.g., perceptions, attitudes, and meanings)	• Bias due to poorly articulated questions • Response bias • Inaccuracies due to poor recall • Reflexivity–interviewee gives what interviewer wants to hear
Direct observations	• Immediacy–covers actions in real time • Contextual–can cover the case's context	• Time-consuming • Selectivity–broad coverage difficult without a team of observers • Reflexivity–actions may proceed differently because they are being observed • Cost–hours needed by human observers
Participant-observation	• *[Same as above for direct observations]* • Insightful into interpersonal behavior and motives	• *[Same as above for direct observations]* • Bias due to participant-observer's manipulation of events
Physical artifacts	• Insightful into cultural features • Insightful into technical operations	• Selectivity • Availability

Table 3: Six Sources of Case Study Evidence.

Source: Yin, 2014

In order to gather primary and secondary data, several sources of evidence were used. Documents, interviews, and observations include the types of information used to gather the case study data. Through the collection of documents and archival files, secondary data was gathered. The use of each source of evidence is as follows:

- <u>Primary Data</u>
  - Interviews
    1. Conducted to corroborate findings.

2. Shorter interview is the type used.
3. Members from each corelated departments chosen as interviewees.
4. Notes used to collect information.

- Direct Observations
    1. Conducted to become more familiar with the Packaging Department.
    2. Completed by shadowing individuals from the Packaging Department (Foremen and operators).

- Secondary Data
    - Documents
        1. Used to complete Theoretical Overview (Chapter 2) that to complete Theoretical Overview (Chapter 2) that serves as the theoretical basis for this thesis.
        2. Consist of Scientific publications and Journal articles.
        3. Found via academic search engines.
    - Archival Records
        1. Used to provide history about the current BOM of the Packaging process.
        2. Found within company's ERP system.

3.4.2 Data analysis

"Data analysis consists of examining, categorizing, tabulating, testing, or otherwise recombining evidence to produce empirically based findings.". (Yin, 2014). It is tough to examine case study results. Case study researchers must follow a methodological approach and use analytical methods in order to prevent problems involved with case study data collection. "The purpose of the analytical strategy is to link your case study data to some concepts of interest, then to have the concepts give you a sense of direction in analyzing the data.". (Yin, 2014)

"Researchers have an opportunity to develop their own analytic strategy or can use one of the four general analytic strategies used for case study analysis. Within any analytic strategy, researchers should choose one of five analytic techniques, and the purpose of the techniques is to assist with establishing case study validity.". (Yin, 2014) "Analytic strategies and techniques help discover relationships and contrasts between variables.". (Gray, 2014)

3.4.2.1 Analytic Strategy

"The best preparation for conducting case study analysis is to have a general analytic strategy". (Yin, 2014) "Four general strategies used to analyze case studies include relying on theoretical propositions, developing a case description, working data from the "ground up", and examining probable rival explanations. Relying on theoretical proposition consists of following the theoretical propositions that lead to the case study. This strategy utilizes the propositions to shape the data collection plan.". (Yin, 2014) "Working data from the ground up consists of evaluating data and organizing data to determine relationships or patterns amongst the data. With the strategy, the researcher plays with the data until correlations are found.". (Yin, 2014) The layout of a case description consists of a case analysis being structured according to a descriptive model. "This strategy is workable in its own right but also serves as an alternative if you are having difficulty using either of the first two strategies.". (Yin, 2014)

"A fourth general analytic strategy (final strategy), trying to define and test plausible rival explanations, generally works with all of the previous three: Initial theoretical propositions (the first strategy) above might have included rival hypotheses; working from the ground up (the second strategy) may produce rival inductive frameworks, and case descriptions (the third strategy) may involve alternative descriptions of the case.". (Yin, 2014)

The empirical method used to complete this analysis focuses on a theoretical premise. This methodology uses the same theoretical method to start the analysis, formulate research topics, impact literature review, and shape data collection. The case study's theoretical proposition is that Lean Six Sigma D.M.A.I.C. methodology can be used to define the root causes of the Bill of Materials (B.O.M.) inefficiency and make recommendations that can be implemented for long-term improvement. D.M.A.I.C. methodology would be used to analyze the project due to the theoretical proposition; thus, relying on the theoretical propositions was considered the most effective methodological analytic approach.

3.4.2.2 Analytic technique

"Analytic techniques are used to develop a case study's internal and external validity.". (Yin, 2014) Pattern matching, explanation building, time-series analysis, logical models, and cross-case synthesis are five methodological methods usually used to analyze case studies. "The logic behind pattern matching is that the patterns to emerge from that data, match those that were expected" (Gray, 2014).

A particular form of pattern matching is known to be explanation building and is most applicable to descriptive case studies. "Here, the goal is to analyze the case study data building an explanation about the case.". (Yin, 2014)

In order to trace variables over time to create patterns, time-series analysis is used. According to Yin (2014), "Whatever the stipulated nature of the time series, the important case study purpose is to examine some relevant "why" and "how" questions about the relationship of the events over time, not merely to observe the time trends alone.". (Yin, 2014)

"Logic models are a combination of pattern matching and time series analysis techniques.". (Gray, 2014) "As an analytic technique, the use of logic models consists of matching cross-case synthesis is an analytic technique that is only applicable to multiple-case studies. Cross-case synthesis treats every individual case study as a separate study and aggregates findings across the studies.". (Yin, 2014).

Pattern matching is the empirical approach that was chosen to complete this study. There are two types of pattern matching: non-equivalent dependent variables as a pattern and rival independent variables as a pattern. "With non-equivalent dependent variables as a pattern, a research study may have several dependent variables or outcomes that emerge from it.". (Gray, 2014) When rival explanations are used, "several cases may be known to have a certain outcome, but there may be uncertainty as to the case, that is, which independent variable is the determining one.". (Gray, 2014) The type of pattern matching chosen for this case study, as a pattern, is non-equivalent dependent variables.

3.5 Research Quality

"Because a research design is supposed to represent a logical set of statements, you also can evaluate the quality of any given design according to certain logical tests.". (Yin, 2014) "The four tests commonly used to judge case studies' quality include construct validity, internal validity, external validity, and reliability. Certain tactics are used to conquer each test, and each tactic occurs within a specific phase of research.". (Yin, 2014).

3.5.1 Construct Validity

"Construct validity has to do with identifying correct operational measures for the concepts being studied.". (Yin, 2014) Multiple sources of evidence, creating a chain of evidence, and making crucial informants review a draft of the case study report are the three strategies used to improve construct validity. "The most critical advantage presented by using multiple sources of evidence is the development of converging lines on inquiry.". (Yin, 2014) It is likely to be considered as more precise and appropriate to base a case analysis on various data sources. "Establishing a chain of evidence also occurs during data collection and allows an external observer to trace the case study's steps from conclusions back to initial research questions or research questions to conclusions.". (Yin, 2014). Chain of evidence can be established by properly citing relevant sources used to arrive at particular conclusions, by ensuring that the conditions in which data is gathered are compliant with the protocols and questions within the case study protocol, and by ensuring that there is a connection between questions about the protocol and original questions about the study. Allowing those interested in the case study to review the paper would help ensure that events and perspectives are correctly documented by researchers. "From a methodological standpoint, the corrections made through this process will enhance the accuracy of the case study, hence increasing the construct validity of the study.". (Yin, 2014)

The techniques used to improve this case study's validity include the use of multiple data and the creation of a chain of evidence. Many of the evidence used to conclude this case study are interviews, direct observations, documents, and archival records. The use of various data and the construction of a chain of evidence amplifies the case study's value to complete this thesis.

3.5.2 Internal Validity

Yin (2014) characterizes internal validity as "seeking to establish a causal relationship whereby certain conditions are believed to lead to other statuses, as distinguished from spurious relationships.". (Yin, 2014)

"If the researcher wrongly concludes that there is a causal relation between x and y without knowing that some third-factor z may have caused y, the research design has failed to deal with some internal validity threat.". (Yin, 2014) "Basically, a case study involves an inference each time an event cannot be directly observed.". (Yin, 2014) "Addressing questions associated with whether or not the inference is correct, whether or not all rival explanations and occasions have been considered, and the concurrence of the data will address the interest associated with inferences made during case studies and increment internal validity.". (Yin, 2014). The analytical approaches listed in previous sections are the methods used to improve internal validity, and during data analysis, these methods occur.

Yin (2014) argued, "If the empirical and predicted patterns appear to be alike, the results can help the case study to strengthen its internal validity.". (Yin, 2014) The application of the Lean Six Sigma D.M.A.I.C. methodology to identify the root causes, make recommendations, and optimize the packaging process's Bill of Materials (B.O.M.) was successful; thus, the expected (theoretical) and case study (empirical) patterns are identical and provide the case study with strong internal validity.

3.5.3 External Validity

"Defining the domain to which a study's findings can be generalized.". (Yin, 2014) The technique used to improve external validity relies on the type of case study selected, and during the design process of the test, the technique takes place. Since this analysis is done with a single-case sample, the tactic used to maximize external validity is the Lean Six Sigma D.M.A.I.C. methodology that will recognize the root cause of an issue and help to establish long-term solutions to permanently mitigate the problem.

"External validity can be strengthened by relating the findings from one or multiple cases back to literature, showing that the results are theoretically feasible or are supported by similar empirical studies.". (Dooley, 2002)

3.5.4 Reliability

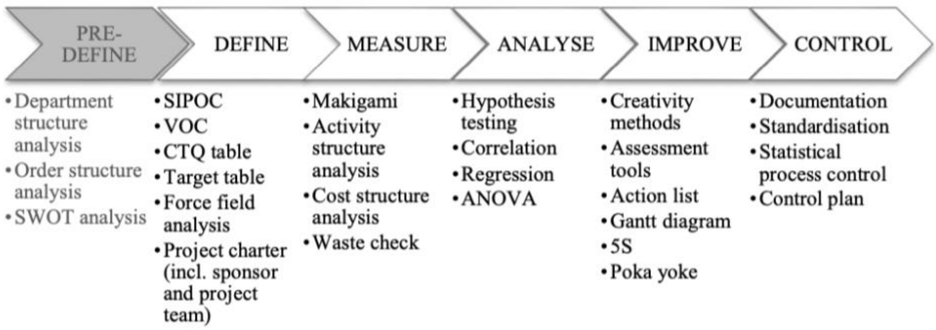
"Demonstrating that the operations of a study – such as the data collection procedures – can be repeated with the same results.". (Yin, 2014) "Two tactics used to increase reliability are using a case study protocol and developing a case study database. These tactics occur during the data collection phase. A case study protocol is prepared to keep the research targeted on the research topic and force the researchers to anticipate adversities. A case study protocol consists of four sections: Section A provides an overview of the case study; Section B provides the procedure used to collect data; Section C provides data collection questions, and Section D provides a guide for the case study report.". (Yin 2014) "The protocol is a major war of increasing the reliability of case study research and is intended to guide the researcher in carrying out the data collection from a single case.". (Yin, 2014)

The organization and documentation of data obtained for a case study comprise a case study's database. This archive contains records and other field-collected materials as well. "The database's main function is to preserve your collected data in a retrievable form.". (Yin, 2014)

4 D.M.A.I.C. Methodology Theoretical Overview

D.M.A.I.C. is the most common systematic approach of Lean Six Sigma. It includes five steps: Pre-define, Define, Measure, Analyze, Improve, and Control (Figure 28). This systematic approach can be described as "A rigorous, step-by-step, logical discipline for defining the most critical business improvement issues, converting them into statistical problems, and then resolving them as standardized daily work practices.". (Watson, 2004). Lean Six Sigma tools will be further analyzed below.

"D.M.A.I.C. offers rough guidelines about which tool to use in which phase. In any case, the project manager can decide to use some tools



in a phase other than D.M.A.I.C. theory advises, to reuse the same tools in different phases, not to use some tools at all or to use additional tools or methods if necessary.". (Unterlechner, 2009).

Figure 28 : The D.M.A.I.C. Process and Tools

Source: George, 2003a

Many experts separate Pre-define from the Define phase in the D.M.A.I.C. methodology. This phase includes selecting and prioritizing the processes to be improved during the improvement project. A process with an obvious problem should be selected, in which potential defects could be identified, resulting in a reduction of costs.

One method that is highly recommended to be used in the Pre-define Phase is a S.W.O.T. department analysis. "With the order structure analysis method's help, we list the department's primary products or services and cluster them in bigger groups. To determine the significance of particular activities, we add information about frequencies (business occurrences) and responsible team members for a particular process. Order structure analysis shows which activity groups are the most frequent in the department. With the help of a prioritization matrix, we rank activities by priorities. The outcome supports identifying the process to select for improvement using Lean Six Sigma.". (Jöbstl and Freisinger 2015).

The process to be improved by the Lean Six Sigma project should be vital either for the customer or the company. "Lean Six Sigma projects have to be organizationally feasible, financially beneficial, and customer-oriented.". (Kwak and Anbari, 2004) Moreover, the problem's solution should still be unknown, and the collection of measurable data is of high importance. "The project scope, resources, and targets should be fixed, and it is recommended that a team carries out the process improvement.". (Jöbstl and Freisinger, 2015)

"In the Define Phase, the requirements and expectations of the customer are specified. The project's boundaries are determined, and the process by mapping the business flow is pictured. At the end of this phase, goals, responsibilities are established, and the project's mission is clear to every customer.". (McClusky in Anbari and Kwak, 2004)

"In the Measure Phase, a data collection plan is implemented. We document and quantify the initial situation by measuring the process. Here the data are collected and compared to determine issues and shortfalls. Hypotheses about the root causes are set.". (McClusky in Anbari and Kwak, 2004)

"In the Analyze Phase, hypotheses, causes of defects, and sources of variation are analyzed. Until this step of the implementation, many improvement opportunities have been found, and in the Analyze Phase, these opportunities are prioritized.". (McClusky in Anbari and Kwak, 2004)

"In the Improve Phase, we enhance the process in order to eliminate variations and develop creative alternatives.". (McClusky in Anbari and Kwak, 2004)

"The Control Phase serves to control process variations to meet customer requirements and develop a strategy to monitor and control the improved process. In this step, we improve systems and structures, introduce a sustainable process solution, and ensure ongoing stability.". (McClusky in Anbari and Kwak, 2004)

In the following chapters, each phase will be explained in more detail. The most commonly used tools and methods in each phase will be presented, and their role will be explained.

4.1 Define Phase

In the Define Phase, the main focus is to identify the problem and define process improvement goals, inputs, and outputs, implementing various L.S.S. tools and methods. It is also specified the customers' nature (external or internal) and their expectations and requirements. "These requirements are systemically analyzed and set measurable targets (Critical to Quality – C.T.Q.) to meet these needs better. A project plan is defined, and the project's start (kick-off) is communicated.". (Jöbstl and Freisinger, 2015) Table 5 lists the tasks and tools used in the Define Phase, and in Figure 29, we summarize the main outputs of the Define Phase.

Activity	Tool
Definition of the process which was selected to be improved	SIPOC
Understand customer requirements within the process	VOC
Definition of measurable CTQs	CTQ table
Definition of the project goals (including measurable target values)	Target table
Calculation of potential cost savings	
Analyse driving and inhibiting forces, make a plan for how to reduce the inhibiting forces and increase the driving forces	Force field analysis
Plan the project	Project definition sheet/Project charter
Release the project by presenting it to the sponsor	Project definition sheet/Project charter

Table 4: Lean Six Sigma Define Phase – Detailed activities and Tools

Source: A.M.T. successfactory, 2015

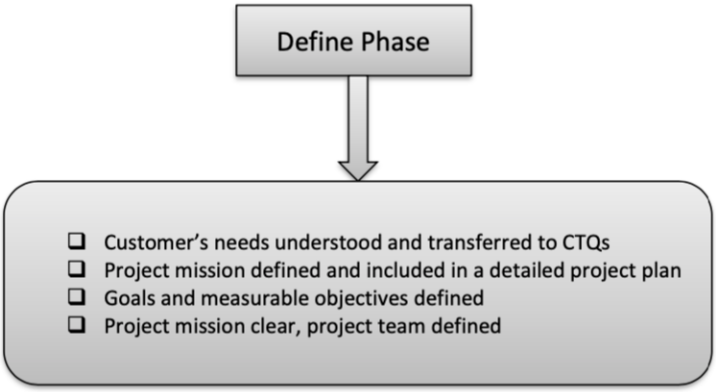


Figure 29 : Main Outputs of the Define Phase

Source: Jöbstl and Freisinger, 2015

4.1.1 Project Charter

A project charter is a typically short document that includes the objectives, milestones throughout the project, how the project will be implemented, and who the stakeholders are.

Furthermore, it summarizes the project teams as well as the relationship between them. "With the help of the Define phase tools, we identify process partners' requirements and convert these requirements to C.T.Q. We define the project scope and benefits of implementation. We execute the first workshops with the project team and present the project charter to the project sponsor.". (A.M.T. successfactory and Uckert Sigma Consulting, 2015)

4.1.2 SIPOC (Supplier-Input-Process-Output-Customer)

A S.I.P.O.C. diagram is a tool that offers an overview of the project to the members that participate in its execution. It helps them to understand the project's borders, the interdependencies between the process steps, and who else is involved in the process. Since "a critical goal of Lean Six Sigma is to satisfy the customer, drawing a S.I.P.O.C. (Suppliers- Inputs-Process-Outputs-Customers) map is the first recommended tool executed to allow a high-level process view of how a particular customer requirement is satisfied. S.I.P.O.C. helps identify the scope of the project.". (Mandahawi, 2011).

In a S.I.P.O.C. diagram Suppliers applies to people, processes, company, or departments, which provide inputs into the project. The term "input" signifies the material or information provided. The process determines all the steps used for a transfer. Finally, outputs (products or services) are delivered to the customer. "By listing all customers of the process, we can already in this step add in information concerning the significant requirements of a particular customer/customer group.". (George, 2003).

"The S.I.P.O.C. diagram provides a visual view of the process and facilitates an understanding of what needs to be changed during the process. A SIPOC process map is valuable, especially in non-manufacturing settings because in services process and systematic thinking are not expected.". (Montgomery and Woodall, 2008).

4.1.3 VOC (Voice of Customers)

"Customer satisfaction is a guiding principle while implementing Lean Six Sigma.". (Psychogios, 2012). "A particular supplier offers services to internal customers; these customers are called Process Partners (the reason for this naming is the awareness that everyone inside the company should be working together to serve the ultimate customer best).". (George, 2003).

The voice of customer tool is a tool that helps teams take customer comments (current satisfaction with the product, delivery of the product, or a service that does not exist) and use this information to develop measurable customer requirements. "It is essential to formulate the interviews/questionnaires so that it is easy to provide measurable responses to facilitate quantitative analysis.". (Unterlechner, 2009)

"Before questioning customers, we cluster them in bigger customer groups (not all customer groups need to have the same needs). For a voice of customer analysis, reactive (old reviews, complaints, etc.) or proactive (we perform interviews/send questionnaires to stakeholders within the scope of the improvement project) sources can be used"." (A.M.T. successfactory and Uckert Sigma Consulting, 2015).

4.1.4 CTQ (Critical to Quality)

"V.O.C. results show major customer needs and priorities. C.T.Q.s are the customer's needs, requirements, and expectations about the product or service presented in a measurable and more detailed way. For each C.T.Q. we define a metric and a target value. In other words, general needs translated into more specific measurable needs are C.T.Q.s.". (Jöbstl and Freisinger, 2015).

4.2 Measure Phase

During the Define Phase, the problem was identified, and the process that needs to be optimized was decided. The purpose of the Measure phase is to gather raw data related to the process. After the collection of these data, the project proceeds to the Analyze phase.

"In the Measure Phase, the flow, feedback loops, measurement-control points, and hand-offs across organizational groups are mapped for the processes. With this information's help, the processes can be divided into logical models that provide a quantitative understanding of the process. Then, the process evaluation can be executed. Actual process data should be used to ensure a reliable process evaluation.". (Watson, 2004).

When a company employs a Six Sigma approach, crucial decisions are based on data analysis. As a result, the data collected in the Measure phase affect the outcome of the improvement project. "Lean management and some other improvement methodologies do not analyze the current process so intensively but start already with making improvements in very early stages of the process.".(George, 2003).

"It is common for services in need of data that these data have never been collected before, are unavailable, or do not show what is supposed to be measured.". (George, 2003).

Table 6 includes the most recommended L.S.S. tools and methods for use in the Measure Phase. In Figure 30, we summarize the main outputs of the Measure Phase.

Activity	Tool
Together with the project team perform the first process-oriented analysis to understand the process and collect data	Makigami
Usage of existing data – determine what needs to be known about the process and plan where to look for the data.	Data collection plan
Deep-dive analysis – measure the time for specific activities within the process steps	Time studies, Activity structure analysis
Calculation of the process costs	Process costing
Check the accuracy and reliability of the measurement process by performing appropriate measurement system analysis	MSA (Measurement system analysis)
Usage of suitable techniques for data presentation	Examples: Pareto-Diagram, Histogram, Line diagram, Bar chart, Box Plot, Scatter diagram, Timing chart...
Calculation of suitable statistical parameters to describe average and scattering behaviours	Examples: Sample characteristics; Distribution type – Probability distributions, Process capability, Sigma level
Calculation of suitable lean metrics to illustrate/quantify the problem	Examples: Flow factor, Lead time, Utilisation, Physical lead time, Work in progress, Throughput per time, Capacity, Rolled throughput yield
Implement the first quick wins	Action plan

Table 5: Lean Six Sigma Measure Phase – Detailed activities and Tools

Source: A.M.T. successfactory, 2015

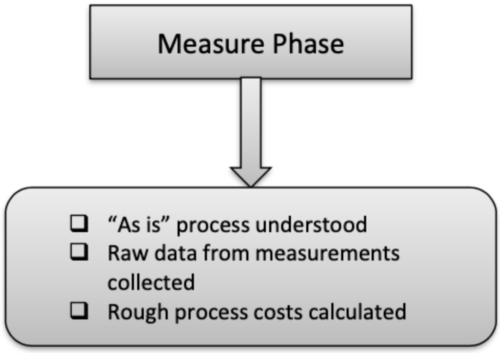


Figure 30 : Main Outputs of the Measure Phase

Source: A.M.T. successfactory, 2015

4.2.1 Makigami (Process Mapping)

Makigami is defined as a process map. "It shows a step-by-step process flow, so it is recommended to draw Makigami with the cooperation of all people involved in the process. Each step is the subject of further analysis. For each process step, we define which function is responsible for performing a particular step. Each activity's total duration in a process step is measured while establishing whether that activity is value-added, non-value-added, or waste.". (Chiarini, 2013).

"For process steps that are more time-consuming and comprise several sub-steps, we can make a deep-dive analysis by investigating sub-steps, e.g., by using Activity structure analysis.". (Jöbstl and Freisinger, 2015)

4.2.2 M.S.A. – Measurement System Analysis

Any process or product measure contains errors. Measurement system analysis is an experimental method that seeks to identify the size of the measurement error. "It is a component of analysis as to how the data were gathered, and the reliability of the data; as the data may be questioned should the team present results that are unpopular.". (Stern, 2016). A good measurement system involves:

- Operator's training and certification
- Standards
- Visual aids
- Established setup procedures
- Established measurement procedures
    - Same place
    - Same light
    - Same standards

Measurement system analysis is implemented using one of the basic types of studies:

- Variable gage study
- Attribute gage study
- Data Audit

This selection is based on the types of data being collected. "A variable gage study looks at two sources of variation and compares them to the magnitude of the measurement being made. These two sources of variation are repeatability and reproducibility.".(Jöbstl and Freisninger, 2015)

"The instrument's repeatability is a measure of the variation obtained when one operator uses the same device repeatedly in order to measure the identical characteristic on the same part. When no operator is present, repeatability accounts for repeat measurements taken on an automated piece of test equipment.".(Jöbstl and Freisninger, 2015)

"The variation in the averages of measurements made by different operators using the same device when measuring identical characteristics of the same parts is called reproducibility. Reproducibility may also be used to quantify differences caused by different measuring devices.".(Jöbstl and Freisninger, 2015) A variable R&R study will quantify the reproducibility of the measurement system.

$$\sigma^2_{total} = \sigma^2_{product} + \sigma^2_{measurement\ system}$$

$$\sigma^2_{total} = \sigma^2_{product} + \sigma^2_{repeatability} + \sigma^2_{reproducibility}$$

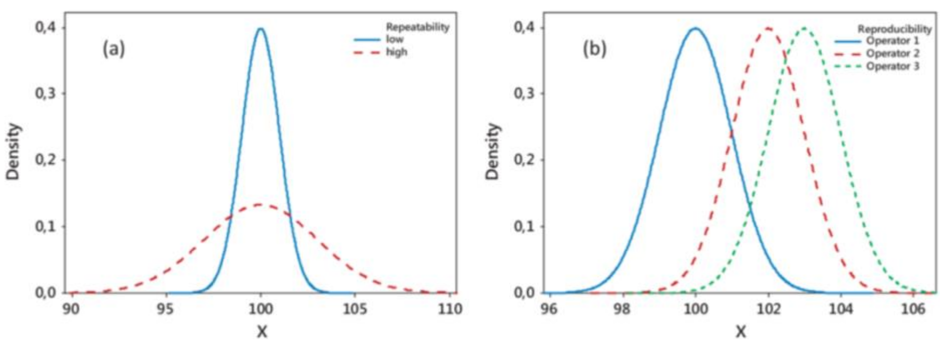


Figure 31: (a) Repeatability and (b) reproducibility on measurement systems.

Source : (Researchgate)

"In an attribute gage study, we use the concepts of repeatability and reproducibility. In an attribute gage study, the "Y" measure is one of the following types: Pass / Fail, Good / Bad, 0 / 1.".(George, 2003)

"In an audit gage study, we want to examine the data's accuracy entered in some "system" as part of our gage assessment.". (George, 2003)

4.2.3 Time studies – Activity structure analysis

"Estimations of time consumed for particular process steps that we gathered with the Makigami tool give us an overview of which process steps are the most time-consuming. For these process steps, we analyze the steps and activities of these sub-steps in greater detail to discover potential improvements. When making a time study, a dedicated person measures all activity times within the observed process step.". (Jöbstl and Freisninger, 2015).

Being aware of the most time-consuming steps is important because "in any slow process, 80% of the delay is caused by less than 20% of the activities. We only need to find and improve the speed of 20% of the process steps to effect an 80% reduction in cycle time and achieve greater than 99% on-time delivery.". (George, 2003)

"Activity structure analysis results also provide initial ideas about possible combinations of tasks such that fewer process loops and interfaces would occur.". (Jöbstl and Freisinger, 2015). "For all employees who record the time of the activities they work on in the process, we prepare daily activity structure analysis forms. Each form for daily recording is completed separately for each day for four weeks. After that, all the daily sheets are summarized in the Activity structure summary.". (Jöbstl and Freisinger, 2015)

4.2.4 Process costing

"The Lean part of Lean Six Sigma is commonly known as a change and improvement method, as well as a cost-reduction mechanism.". (Bicheno and Anchanga in Näslund, 2008). "It strives to raise a company's competitiveness by increasing efficiency and cutting costs by eliminating waste and non-value-adding activities (Motwani in Näslund, 2008), reducing cycle times (Sohal and Egglestone in Näaslund, 2008), and increasing the organization's profit.". (Claycomb in Näslund, 2008) In order to determine the cost savings of the improvement project, the current process cost should be calculated and then compared to the current situation.

"Information about the price per unit (hourly rates), the time needed, and the business occurrence frequency enables us to calculate the process costs. These results show which are the most significant cost drivers and where costs can be reduced.". (Jöbstl and Freisinger, 2015)

4.3 Analyze Phase

During the Measure Phase, the required data from the sub-processes were collected so as to be analyzed during the Analyze phase.

"We identify possible causal relationships between the inputs and C.T.Q.s by analyzing raw data. In this phase, a thorough diagnosis of the current situation is made to identify C.T.Q.'s main factors.". (de Koning, 2008). "We analyze hypotheses on the sources of delay, waste, and low quality, which we set in the Measure Phase.". (George, 2003). Team members need to separate their personal experiences related to the process and focus on the data collected to reach the correct conclusions. "The tools most commonly used for root-cause analysis are the Ishikawa diagram, 5 Why's analysis, Scatter plot, design of experiments, etc.". (George, 2003). Table 7 shows the most frequently used tools of the Analyze Phase and the main outputs.

Activity	Tool
Find additional problems/potential in a systematic way. Use lean principles.	Muda hunt checklist
Search systematically and in the team for all possible causes of the problems identified in Makigami.	Ishikawa diagram, Mind map
Differentiate between “type 1” and “type 2” causes and define hypotheses concerning “type 2” causes	Hypothesis list
Analyse existing data to prove hypotheses with the help of appropriate statistical techniques	Regression analysis, statistical tests, ANOVA
Answer the corresponding hypotheses based on numbers, data and facts (relevant causes shown)	Hypothesis list
Drill to depth relevant causes to ensure the problem was understood	5 Whys analysis
Visualise the results (relevant X) of the analysis phase in the process chain	Makigami

Table 6: Lean Six Sigma Analyze Phase – Detailed activities and Tools

Source: A.M.T. successfactory, 2015

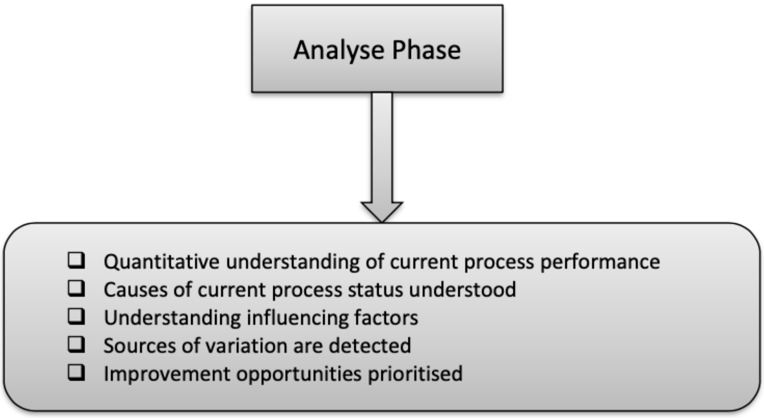


Figure 32: Main Outputs of the Analyze Phase

Source: A.M.T. successfactory, 2015

4.3.1 Muda Hunt Checklist

"The goal of lean processes is to eliminate waste. One tool used to detect waste is the Muda hunt checklist. When we identify waste, we can cluster it within a M.U.D.A. category (e.g., overproduction, waiting, loops, etc.).". (Arnheiter and Maleyeff, 2005). "When waste and the appropriate category are defined, we ask questions about the waste detected (e.g., Why do we receive so many résumés of unqualified candidates? Why do so many candidates drop out after visiting our town?). After waste is detected, classified, and analyzed, we derive improvement actions.". (A.M.T. successfactory and Uckert Sigma Consulting, 2016).

4.3.2 Fishbone Diagram

A Fishbone diagram is also called Ishikawa diagram due to Kaoru Ishikawa and presents the potential causes. The problem that concerns the project is presented as the fish's head, and the causes of this defect as fishbones. "Each category of causes is then subdivided again into causes. Another example of categories of causes could be processes, technology, knowledge, information systems.". (Beckford, 2002) "An Ishikawa diagram is usually a product of team brainstorming about the problem in question.". (Wong, 2011)

4.3.3 Types of Inputs (Xs), White and Black-box model, and a Hypothesis

There are two types of inputs (Xs). "The first group of Xs affects Y and is easy to change. Under the condition that X affects Y and that this X is essential, we can move to the next step in the D.M.A.I.C. model – the Improve Phase. Suppose it is unclear how X affects Y. In that case, hypotheses are defined, and by analyzing raw data gathered in the Measure Phase, we conduct a deep-dive analysis.". (A.M.T. successfactory and Uckert Sigma Consulting, 2016).

"When setting hypotheses, we can use the white-box or the black-box approach. White box refers to a known area, to experiences, while black box refers to something unknown for which we have to perform experiments. We use as many details as possible, taking every factor into account. The black-box model is a determination-free model – using a mathematical approach to find cause-effect relationships. Such an approach only uses the primary cause to explain the effect.". (Rosi, 2012); However, "a strong mathematical or graphical relationship between variables is not yet proof that one variable was caused by another. In addition to a statistically significant relationship, knowledge about the process must support this causal relationship (a combination of the white-box and black-box approaches when analyzing).". (Rosi, 2012; A.M.T. successfactory and Uckert Sigma Consulting, 2016).

4.3.4 Scatter plot

A scatter plot is a graph that presents with dots two different measurable variables. "A scatter plot cannot predict cause-effect relationships, but can also indicate a possible positive, negative, or zero correlation between two variables.". (Basu, 2009). "With a scatter plot, we can conclude if two factors are connected, but the relationship's degree can only be quantified by other statistical tools (e.g., regression analysis).". (George, 2003).

4.4 Improve Phase

Subsequent to completing the Measure and Analyze phases, all necessary information has been gathered, as well the defects regarding the process that needs to be improved have been identified. "In rare cases, the process performance is so bad that the team decides to apply the D.M.A.D.V. (Define-Measure-Analyze-Design-Verify) methodology instead of the D.M.A.I.C. to design and verify a new process instead of improving and controlling the existing one.". (Albeanu, 2010)

"A vital element of the Improve Phase is change management. It can apply to the process activities of the team members involved or the technology in use. Since following the Lean Six Sigma methodology, the impact on the staff and customers involved is typically significant, and change management strategies must be developed.". (Albeanu, 2010)

"In the Improve Phase, actions to modify the process, or settings of influence factors are designed so that the C.T.Q.s are optimized, and pilot tests of improvement actions are conducted.". (De Mast and Lokkerbol, 2012). "The process is improved by eliminating the root causes and controlling the process to ensure defects do not reappear.". (Pojasek in Näslund, 2008). "A stable process is the primary purpose of Six Sigma projects, so the Improve Phase holds great importance in the D.M.A.I.C. model.". (Pyzdek in De Koning, 2006)

Table 8 summarizes the most commonly used L.S.S. tools and methods in the Improve Phase. The main outputs of the Improve Phase are demonstrated in Figure 32.

Activity	Tool
In a team write down a list of innovative ideas for possible solutions for all relevant causes	10 point checklist, creativity techniques, (Brainstorming, 6-3-6 progressive abstraction, 6 hats)
Use suitable lean management methods to develop solutions	Poka yoke, 5S, Kanban, Controlling/Planning, Prioritising rules, Segmenting, One piece flow, Incentive systems
Develop and draw the "to be" process	Makigami
Assess the ideas using criteria	Cost-benefit matrix
Match the solution with a sponsor/manager/champion and receive their approval	
Develop a plan for implementing the solution, action plan, assessment of the results, schedule	Action plan, Gantt diagram

Table 7: Lean Six Sigma Improve Phase – Detailed activities and Tools

Source: A.M.T. successfactory, 2015

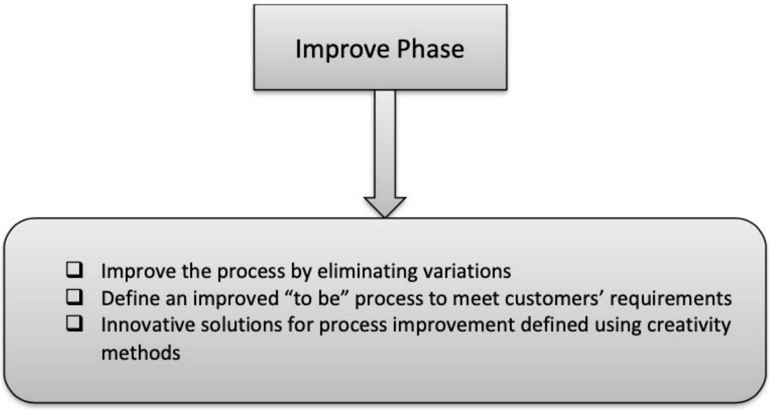


Figure 33: Main Outputs of the Improve Phase

Source: A.M.T. successfactory, 2015

4.4.1 "To be"-Process definition: 10-Point checklist

A 10-Point checklist provides us with a step-by-step method to identify potential waste throughout the process.

1. "Create values without waste – What is needed by our customers? Keep effectiveness in mind first. Avoid over-processing. Question the tasks as such. Divide the tasks into value-adding and non-value-adding.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

2. "Reduce and define interfaces – Information changes when it is passed on. Reduce interfaces with a Makigami flowchart.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

3. "Minimize follow-up questions and rework – Can we reduce the loops and failures? The chief causes of queries and mistakes in administration are a lack of information, unclear/unspecific information, unclear distribution of competencies and tasks, constant change in the process, and lack of coordination. Use the Poka-yoke principle – designed processes so that mistakes are impossible or at least easily detected and corrected.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

4. "Eliminate bottlenecks – With the help of a Makigami analysis and activity structure analysis, define any bottlenecks.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

5. "Shorten approval loops – Can we reduce the time to approval? Is the whole approval chain needed? Can we reduce the number of approvers.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

6. "Define information requirements – Which information needs to be transferred from one step to another? Information needs to be provided in a needs-related manner – use standardized templates for information transfer.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

7. "Identify important decision points in the workflow – many business processes have one or more points that are very decisive for how the process will proceed from that point on. These decision points must be considered and optimized.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

8. "Enable parallel work – Can the lead time be shortened if we execute some steps simultaneously.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

9. "Establish a needs-driven process – Can we change the push principle to a pull principle? Only provide services actually needed by the following point in the process.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)
10. "Smooth service delivery process – Can the input be balanced better? Balance the input, make it more stable – with fewer deviations.".(Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting 2016)

Each of the presented points includes practices from the lean methodology. The 10-point checklist is suggested to be used at the beginning of the Improve phase and is efficient to be combined with other methods, such as brainstorming among the project members.

4.4.2 Poka-Yoke

"Poka-yoke is a zero-defect process standard developed by Shigeo Shingo for manufacturing processes where the operation is terminated when a defect is detected and the process rectified before it is restarted.". (Beckford, 2002) Poka-yoke is a Japanese term that means mistake-proofing. "A Poka-yoke is any mechanism that helps an operator prevent (yokeru) mistakes (poka) by eliminating the root cause of the expected error in the process. Poka-yoke's fundamental idea is to design a process this way that mistakes are impossible (striving for zero defects) or at least where mistakes are easily detected and corrected.". (Robinson 1997; A.M.T. successfactory and Uckert Sigma Consulting, 2016)

4.4.3 5S

"5S stands for Seiri (sort; put into order), which means only keeping the items you need and discarding the rest. Seiton (set; arrange) implies arranging kept things efficiently and setting them in order. There should be a place for everything, and everything should be in its place. Seiso (shine; clean) helps prevent problems by keeping things clean. Seiketsu (standardize) refers to after-work maintenance and clean-up. Operating consistently brings consistent results. Shitsuke (sustain) means showing discipline, following the rules, and maintaining standards.". (George, 2003; Näslund, 2008; Uma, 2010)

"Introducing the concepts of standardized procedures and workplace improvement following 5S can improve efficiency and responsiveness, which results in cost reduction.". (Liker and Wu, 2000)

4.5 Control Phase

In the Improve Phase, we enhanced the system to become capable and in line with the customer's requirements. "In the Control Phase, we develop control systems to ensure that the improvements are maintained, and the newly improved process can be executed in day-to-day operations.". (De Koning et al., 2006) "In this Phase, a process owner takes over measurements of the process performance. In some cases, adjustments of I.T. systems in use might be necessary to generate control reports. Control procedures must be simple and easy to use, and control metrics should be easy to understand. Data collection has to be automated as much as possible.". (Albeanu, 2010)

During this phase, all necessary improvements to the process have been made, and "the project leader (in most cases, a Lean Six Sigma champion or black belt certified person) hands over the process performance measurement tasks to the process owner. For a smoother handover, it is recommended that the process owner is already involved in the previous stages of the project.". (George, 2003) "The process transfer is done after the improved process has been thoroughly documented and the process owners are well trained on how to control it.". (Albeanu, 2010) "Project results are empirically verified, and the control system is adjusted so that the process improvement can be sustainable.". (De Mast and Lokkerbol, 2012)

Employing Lean Six Sigma tools, the ongoing process performance is measured. "Project results are empirically verified, and the control system is adjusted so that the process improvement can be sustainable.". (De Mast and Lokkerbol, 2012).

"One of the Control Phase's significant activities is selecting control metrics that enable tracking the process efficiency and effectiveness after implementing the improvement process. Dashboards can be used for controlling the process control. Besides, in the Control Phase, the intensity of training and communication about the renewed process is further increased to ensure a smooth ownership transfer.". (Albeanu, 2010) Table 9 presents the Control Phase's main activities as well the tools and methods implemented. Figure 34 gives a short overview of the outputs of the Control phase.

Activity	**Tool**
Collect all data that confirm the objective was achieved	Linediagram, Bar chart, statistical tests
Monitor the non-targets and ensure that other key figures have not deteriorated	
Select additional measures to monitor the process performance and to ensure the optimised process' future effectiveness	Statistical process control (SPC) or control charts
Ensure appropriate visualisation and standards to ensure the solution is lived in the future	Visual management, Standardised work (integration in Quality management system, Control of documents, ...)
Prepare documentation on the changed process, including the responsibilities	Flow chart
Choose the "owner" of the process which will take responsibility for the optimised process and ensure the continuous implementation of the measures	
Prepare a report that documents the team's work and the data collected during the project and pass this knowledge on to other team members	
Announce other issues and opportunities that previously could not be submitted to top management (Lessons Learned, Review)	
Celebrate the hard work and successful activity of the team	

Table 8: Lean Six Sigma Control Phase – Detailed activities and Tools

Source: A.M.T. successfactory, 2015

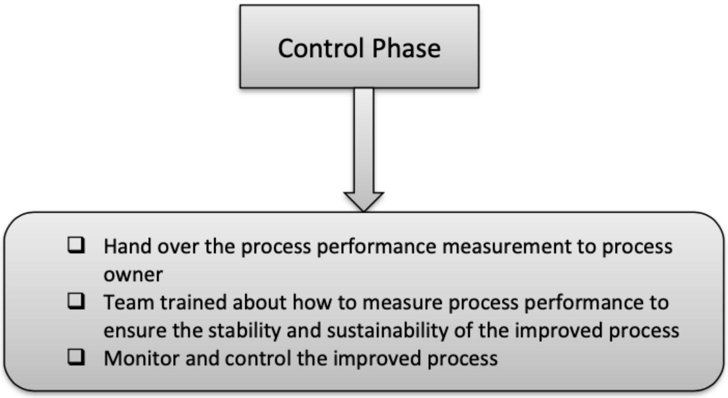


Figure 34: Main Outputs of the Control Phase

Source: A.M.T. successfactory, 2015

4.5.1 Trend Charts

Trend charts are used to confirm trends in process performance over time. "In the Control Phase, they are used to monitor and control the process performance and communicate findings. Three main types of patterns to look for when interpreting run charts are:

Runs – any series of eight points that are not on the median or in its close proximity.

Trends – any sequence of seven or more points increasing or decreasing in value.

Cycles – any other pattern that recurs eight times or more.". (Albeanu, 2010)

"By plotting data over time, we learn about trends, patterns, and data variation in time. Run chart data allow us to study the effect of improvement efforts. As shown in Figure 35, the horizontal line in the middle presents the median – it divides the data points into halves.". (Anhøj and Olsen, 2014)

Figure 35: Trend Chart

Source: Anhøj and Olsen, 2014

4.5.2 Control Charts

"Suppose the data are chaotic, and the process is not in statistical control. In that case, the focus in the Analyse Phase should be on identifying those things that cause the majority of issues and not concentrating on the outliers.". (Williams, 1994; Albeanu, 2010). "Control charts are useful for continuous optimization and control of a process that is already within control limits.". (Anhøj and Olsen, 2014)

"A control chart can show that a process is within the control limits, yet the average of the points is too high or too low, or the variation bigger than desired. Control charts can help identify what the root cause of special status in the process is, and based on this fact, and corrective actions can be planned.". (Williams, 1994).).

4.5.3 Capability analysis

"Once a process is under statistical control and produces consistent and predictable outputs, we can use capability assessment tools to study the process outputs against the required specifications.". (Albeanu, 2010)

"The process is capable if it falls within the specification limits when it delivers the quality the customer requires, and the error rates are lower than agreed.". (Albeanu, 2010) "We visually present a capable process in Figures 14,16 of chapter 2.2.2. "The final goal is that the process is capable and controlled.". (A.M.T. successfactory and Uckert Sigma Consulting, 2016).

Capability analysis consists of two components:

- "A capability histogram shows the distribution of outputs of the process, the upper and lower limits, as presented in Figure 35.". (Albeanu, 2010)

- "Capability ratios/indices (Cp, Cpk) – numerical values that estimate the process's capability in considering the upper and lower limits. The values show how well a process that is under control performs within the specification limits.". (Albeanu, 2010)

"Cp – shows the process's precision relative to specified tolerances. In other words, it shows the allowed variation of the process and its actual variation. The lower the Cp value, the more outputs fall out of the specification limits. We picture different value ranges for Cp in Figure 36.". (Albeanu, 2010)

"Cpk – shows precision and position. It considers whether the process is centered or not (if there is an unwanted offset or not). It shows how close the process is delivering within the limits of the specification. The larger the Cpk, the lower the number of occurrences outside the specification limits.". (Albeanu, 2010)

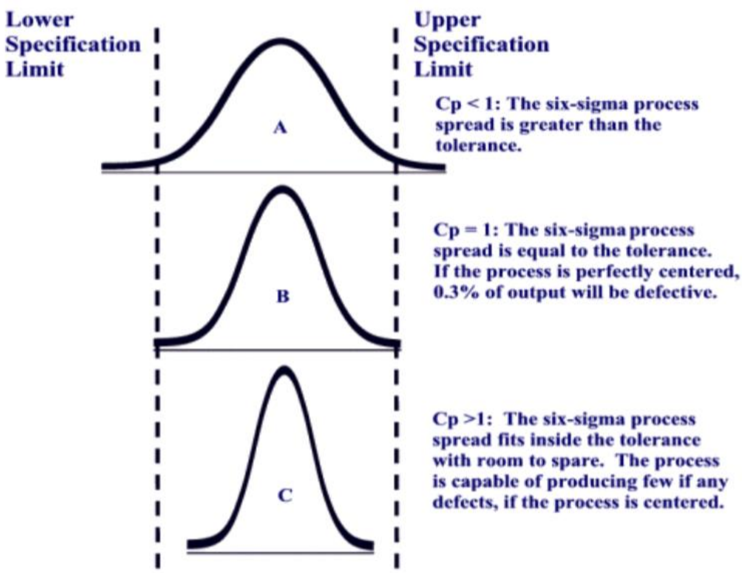


Figure 36: Capability Histogram in relation to the value of Cp

Source: Statistical Process Control-S.P.C.

5 D.M.A.I.C. Project execution

The previous section provided the theoretical background of the Lean Six Sigma method and, in particular, the D.M.A.I.C. methodology. All the necessary tools that can be used during each phase of the project were identified as well as the benefits we derive from their use.

The primary purpose of the practical part of the research is to prove that the existing bill of materials presents incorrect data as well as the delivery of new updated tables. This can be demonstrated by using the necessary Lean Six Sigma tools and methods and showing their application in each phase of the improvement project, which contributes to redefining the packaging process's bill of materials.

The tools and methods used in the Define, Measure, Analyze, Improve phases will be demonstrated, as well as the tools and methods planned for the Control phase. The main purpose is to offer an updated B.O.M. with the right materials and exact quantities and implement improvements to reduce potential waste. The project's primary goal is that the improved B.O.M. will lead to the identification of all packaging materials and their quantities in order for the costing process to be accurate and immediate. (Approximate profit EUR 6.000) The project's secondary goal includes better inventory management and a significant reduction in the time needed for B.O.M. formatting. (Approximate profit EUR 6.000)

Lean Six Sigma offers various tools and methods that can be used during an improvement project. "Depending on the circumstances and needs of a project, Lean Six Sigma offers flexibility in deciding which tools to use in a particular project stage. Besides, Lean Six Sigma encourages users to slightly adjust the tools to a project's needs if necessary.". (George, 2003)

5.1 Lean Six Sigma Application in HALCOR S.A.

Halcor S.A., in order to maintain the position of power, ensures high quality in production through strict controls applied throughout the production process. With a consistent quality focus, the company implements an ISO 9001: 2015 Certified Quality Management System and utilizes high technologies and specialized personnel.

Halcor S.A. has developed consistently and responsibly based on a customer-centric approach. It aims to maintain long-term partnerships with its customers, closely monitor the market, and develop synergies to meet their specialized and ever-changing needs successfully.

Besides, with a stable and responsible commercial policy, it implements a clear strategy that focuses on extroversion, productive flexibility, and the continuous upgrading of the quality and the solutions provided to its customers, thus building long-term trust relationships.

Finally, the company seeks the continuous improvement of its employees, adopting a culture of continuous improvement (CI), investing in modern technology, always emphasizing quality and competitiveness. In recent years the company has invested significantly in its human resources, organizing seminars on the Lean Six Sigma method. The primary purpose of these seminars is to encourage its employees to make decisions based on data and not based on previous experiences and knowledge, as well as the existence of a common communication code when company members need to work on a project.

5.2 D.M.A.I.C. Methodology – Optimization of B.O.M.

In the following stages of the dissertation, all the Lean Six Sigma methods and tools used in each of the five phases of the improvement project, are listed as well as the impact they had on the final configuration of the bill of materials.

5.2.1 Define Phase

During this phase, the project's purpose was determined, the improvements we expect to be achieved, the team called upon to implement it, and its inputs - outputs. They also identified who our "customers" are - internal or external customers - and their requirements. Below are some of the L.S.S. tools we adopted during the implementation of the Define phase.

- Project Charter

The Project Charter is a document where all the important events of the project are summarized. First, the problem is listed, then the goal set, the members that make up the project, and the possible benefits from its completion. In our case, all these crucial decisions were made by the project manager when we were assigned the improvement project.

1. Problem Statement
    - Due to an obsolete B.O.M., the precise costing of the product can not be achieved. Problems associated with the inventory of the packaging materials and additional workload in other departments had also emerged.
2. Project's Goal
    - The project's primary goal is to update the B.O.M. to the product's costing to be accurate and immediate.
    - The project's secondary goal is to prevent excessive B.O.M. formatting distributed in other departments and provide better inventory management.

3. Project Team Members
    - Lean Six Sigma Black Belt (1)
    - Lean Six Sigma Green Belt (1)
    - Lean Six Sigma Yellow Belt (1)
    - Financial Department Personnel (1)
    - Product Design Department Personnel (2)
    - Materials Department Personnel (1)

4. Communication Plan
    - Start date: 17.07.2020
    - Define: 19.08.2020

- Kick-off: 31.08.2020
- Measure: 14.09.2020
- Analyze: 22.09.2020
- Improve: 02.10.2020
- Control: Will be implemented the next six months.
- Lessons learned and summary: -
- End date: -

5. Initial Measures
    - Elimination of waste throughout the packaging process (estimated EUR 6000 savings)
    - Reduction in the time provided for B.O.M. formatting and better management of inventory (estimated EUR 6000/year savings)

- Stakeholder Analysis

Stakeholder analysis involves people or organizations that can affect the change or be affected (stakeholders). Identifying the major stakeholders, investigating their roles, interests, relative power, and desire to participate is part of the stakeholder analysis. The project's major stakeholders are the Packaging Department, the Product Design Department, the Materials Department, and the Financial Department.

As presented in Table 10, the level of commitment of each key stakeholder is scaled in eight categories as follows:

1. Enthusiastic support - Stakeholders will work hard to make it happen.

2. Help it work - Stakeholder will lend appropriate support
3. Hesitant - Stakeholder holds some reservations and will not volunteer to help.
4. Indifferent – Stakeholders will not help; will not hurt.
5. Uncooperative - Stakeholders will have to be probed in order to help.
6. Opposed - Stakeholders will openly act on and state opposition.
7. Hostile - Stakeholders will block all efforts at any cost.
8. Not yet informed - Stakeholder will involve when appropriate.

With **X,** we define where their level of commitment is, and with ●, where we want them to be.

Level of Commitment	Packaging Department	Product Design Department	Materials Department	Financial Department
Enthusiastic support	X ●		●	●
Help it Work		X ●	X	X
Hesitant				
Indifferent				
Uncooperative				
Opposed				
Hostile				
Not yet informed				

Table 9: Stakeholder Analysis

Source: Authors Table

The stakeholder analysis indicates that the Packaging and the Product Design Department were meeting our expectations, in contrast to the Materials and Financial Department below where we want them to be.

- Order Structure Analysis (with ABC Analysis)

In order to reach conclusions regarding our sub-processes in the Packaging department, the Order structure analysis tool was applied. As a result, we initially overviewed these sub-processes into groups of similar data outputs. We defined the required materials for each activity and classified their data outputs into two categories: Activities that provide attribute data and activities that provide variable data (through measurements). The activities that their outputs provide variable data are marked "A", those that provide variable data but are strictly standardized are marked "B" activities, and those that provide attribute data are marked with "C". The detailed process map will be presented in the Measure Phase with the makigami process map.

Besides, we also asked the operators which activities during the packaging process are not well-defined through particular work instructions and materials. All information gathered helped distinguish the most critical activities among the rest and focus on them during the Measure phase.

- S.I.P.O.C. Process Map

In most companies, each employee is responsible for part of the process. Therefore, the holistic view of the process is not always understood. A S.I.P.O.C. process map has the primary goal of presenting who the suppliers and customers are and the requirements formed between them.

Table 10 demonstrates that customers and suppliers relate to the company's internal departments, while in some cases, a department may have the role of both customer and supplier. This is mainly due to the project's nature, which mainly concerns eliminating waste and not the product's final quality.

Suppliers	Input	Process	Output	Customers	Customer Requirements
Packaging Dep	Database information Packaging Process Map	Observation of the Packaging process	Activities identified	Materials department	Right identification of the activities of the process.
Materials Dep.	Database information	Collect detailed lists with materials' information	Detailed data collected	Packaging Dep	Check information's validity.
Financial Dep.	Database information				
Packaging Dep	Database information Packaging Process Map	Define the materials required for each packaging type	Detailed data collected	Materials Dep.	Right identification of material's id and description
Materials Dep.	Database information	Define the quantities of the materials.	Detailed data collected	Packaging Dep	Accurate measurements

Packaging Dep	Operators training	Ensure measurements validity, by setting specifications.	Data validity secured	Product Design Dep.	Meet certain B.O.M. specifications.
Product Design Dep.	Database information B.O.M. specifications	Update B.O.M.	Updated B.O.M.	Company	Financial results

Table 10: S.I.P.O.C. Process Map

Source: Authors Table

- <u>V.O.C. – Voice of Customers</u>

To better understand our internal customers' requirements, we must first consider their beliefs on the current situation. We asked them what, in their opinion, were the main issues of the problem, and which are the outdated supplements of the B.O.M.

Table 12 below summarizes our plan before starting the research on performing the Voice of Customer research.

WHO	WHAT &WHY
Department Managers	We will consider customers satisfaction with the current B.O.M. We will ask questions related to efficiency, quality and their expectations.
SUMMARY	
A meeting with all of the Project's Stakeholders will be conducted. They will provide their insight into the problem, and mention their requirements.	

Table 11: V.O.C. Communication plan

Source: Authors Table

The Voice of Customers includes the following statements:

- "I think that the main issue does concern the quantities of materials used, for every packaging type. The quantities of the materials that exist in the current Bill of Materials are outdated, so there is a high possibility the final costing of the packaging department to be completely inaccurate." – *Financial Department Manager*

- "I think the most significant issue is that the current Bill of Materials does not include certain information for some materials, leading to daily B.O.M. formatting to our department." – *Product Design Department Manager*

- "I think the biggest issue does concern the supplies of the packaging materials. We need to monitor our inventory periodically in order to avoid material shortages." – *Materials Department Manager*

- C.T.Q. – Critical to Quality

Considering all the statements that preceded the customer requirements and their suggestions for possible causes leading to this problem, we are urged to turn them into C.T.Q. objectives. As we illustrated with the S.I.P.O.C. process map in Table 10, various internal customers are involved in our process. In the C.T.Q., we focus on our customer requirements; The most crucial requirement analyzed in the Measure Phase concerns accurate measurements.

5.2.2 Measure Phase

During the Measure Phase of our project, the tools used include Makigami process mapping, Pareto Charts, and Measurement System Analysis. When analyzing the process steps, we identified the essential activities of the packaging process. We performed a deep-dive analysis to identify which activities in the process steps provide us variable and which attribute data to examine them through the Measurement System Analysis further.

- Makigami Process Map

The Makigami process map was used to define the sequence between processes in the packaging department. Through the creation of this diagram, the main goal is to identify processes that during their execution need packaging materials. Procedures that require material consumption to be completed are denoted as VA (Value-added) and are the processes that are subject to measurement.

As presented in chapter 5.2.1, it is also highly important to distinguish each activity into particular data categories. For each process step, we added information about executing each particular process step and classifying them in one of the categories mentioned. By doing so, we gathered process steps. The process map of the packaging process and the detailed Process Maps of each packaging type are presented in Figures 37, 38, 39, 40.

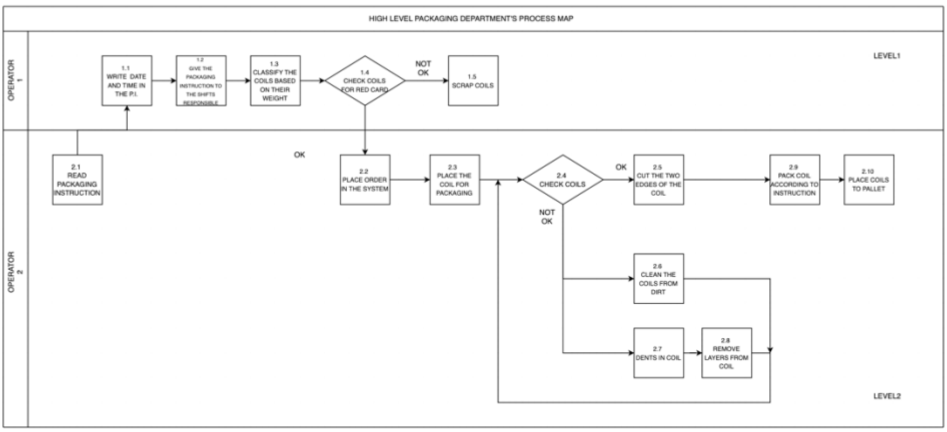


Figure 37: High Level Process Map of the Packaging Process

Source: Authors Figure

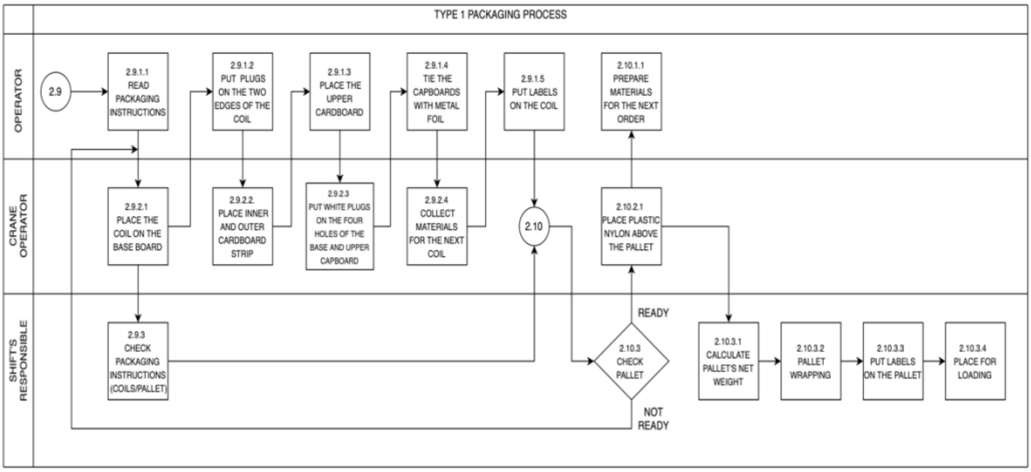


Figure 38: Detailed Process: Packaging TYPE 1 (Full Packing)

Source: Authors Figure

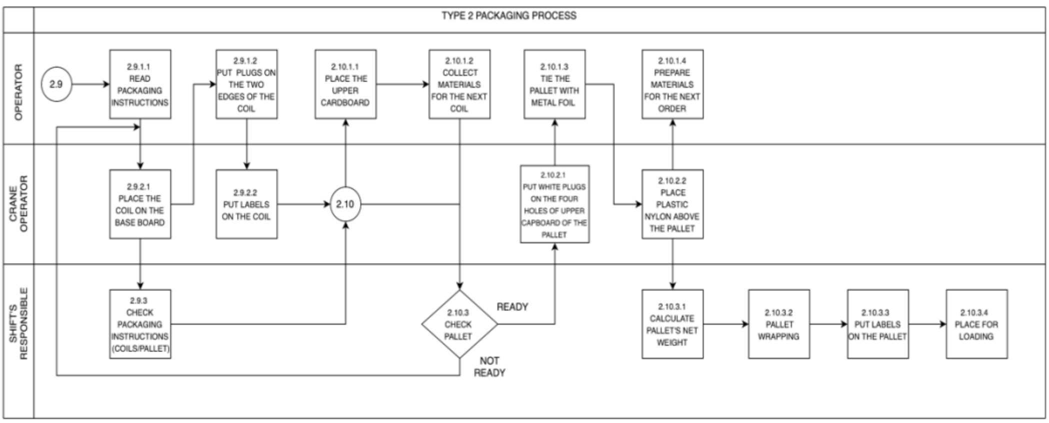


Figure 39: Detailed Process: Packaging TYPE 2 (Simple Packing)

Source: Authors Figure

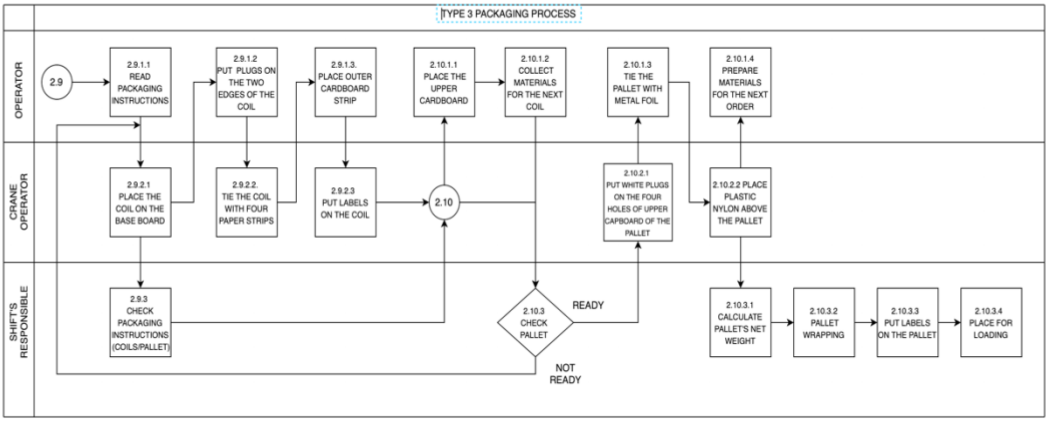


Figure 40: Detailed Process: Packaging TYPE 3 (Packing using paper tape)

Source: Authors Figure

- <u>XY Matrix</u>

The XY matrix is a table, which presents the critical outputs (Outputs-Ys) of the Project and the various inputs (Inputs-Xs) that affect them. Creating an XY chart allows the Project team to determine the most critical outputs and rate them on a scale of 1-10 based on their impact on the customer. Finally, the team is asked to evaluate each input's influence on these outputs to identify the inputs that should be of interest. Below are Figure 41,42 showing the results of the XY Matrix. As presented in both figures below; the most crucial sub-process is the pallet wrapping with stretch film.

XY Matrix

Project: Update BOM

Date: 11/10/20

	Input Variables (X's)	1	2	3	4	5	Rank	% Rank
	Output Variables (Y's)	Accurate Measurements	Waste during Measurements					
	Output Rating	10	8					
		Association Table						
1	Place the coil on the base board	0	0					
2	Put plugs on the two edges of the coil	0	0					
3	Place inner and outer cardboard strip	3	2				46	14,20%
4	Place the upper cardboard	0	0					
5	base cardboard	0	0					
6	Tie the cardboards with metal foil	4	0				40	12,35%
7	Put labels on each coil	0	0					
8	Place plastic nylon above the pallet	6	2				76	23,46%
9	Pallet wrapping with stretch film	9	9				162	50,00%
10	Put labels on the pallet	0	0					

Figure 41: XY Matrix (Full Packing)

Source: Authors Table

Update BOM

11/10/20

Output Variables	Customer Priority Rating
Accurate Measurements	10
Waste during Measurements	8

Initial Order

Input Variables	Output Rating	%
Place the coil on the base board		
Put plugs on the two edges of the coil		
Place inner and outer cardboard strip	46	14,20%
Place the upper cardboard		
Put white plugs on the four holes of the upper and base cardboard		
Tie the cardboards with metal foil	40	12,35%
Put labels on each coil		
Place plastic nylon above the pallet	76	23,46%
Pallet wrapping with stretch film	162	50,00%
Put labels on the pallet		

Sorted Order

Input Variables	Output Rating	%
Pallet wrapping with stretch film	162	50,00%
Place plastic nylon above the pallet	76	23,46%
Place inner and outer cardboard strip	46	14,20%
Tie the cardboards with metal foil	40	12,35%
Put white plugs on the four holes of the upper and base cardboard		
Put labels on each coil		
Put labels on the pallet		
Place the coil on the base board		
Put plugs on the two edges of the coil		
Place the upper cardboard		

Figure 42: XY Matrix results (Full Packing)

Source: Authors Table

- <u>Pareto charts</u>

"A Pareto chart organizes data to show major factors that make up the subject being analyzed. It is used to display information about the X's that influence the Y. The bars in a Pareto chart are arranged side by side in descending order from the y-axis. The basis for Pareto analysis is the 80-20 rule; 80% of the problems result from 20% of the causes.

A Pareto chart is used to highlight the vital few in contrast to the trivial many. Selecting categories, tabulating data, ordering data, and constructing the Pareto chart can enhance team members' communication.". (George, 2003)

In this thesis, Pareto charts are used to identify major factors that influence our measurements. In Figure 37, the packaging type preferences

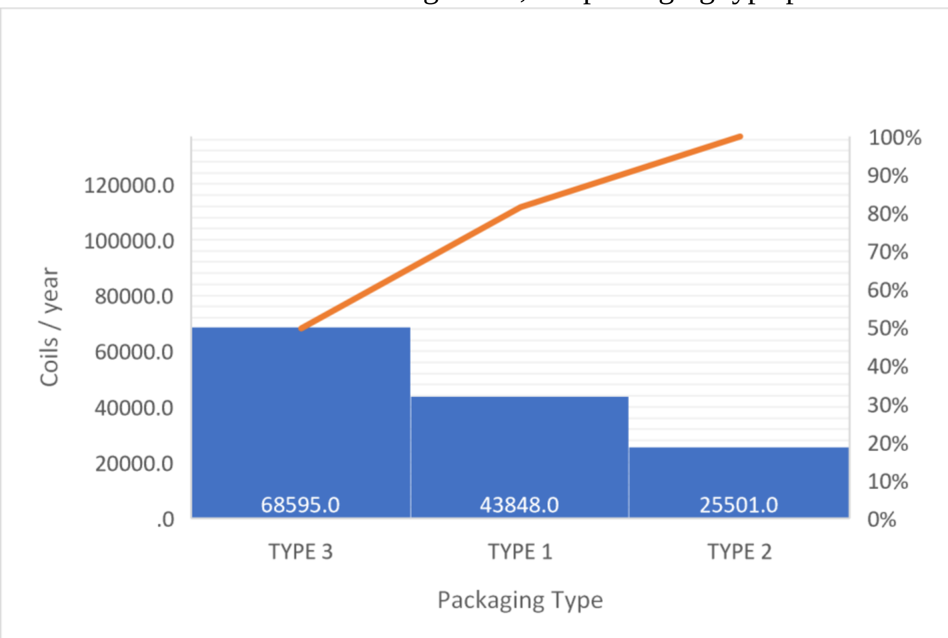


Figure 43: Packaging type preferences

Source: Authors Figure

are presented. This figure provides us with valuable information about the packaging type preferences, prioritizing our measures.

In figure 38, the activities associated with the packaging process are presented. This figure provides us with information about the total number of activities of each packaging type, gives us an insight into the distribution of activities for each data category, and helped us organize the next steps of the project.

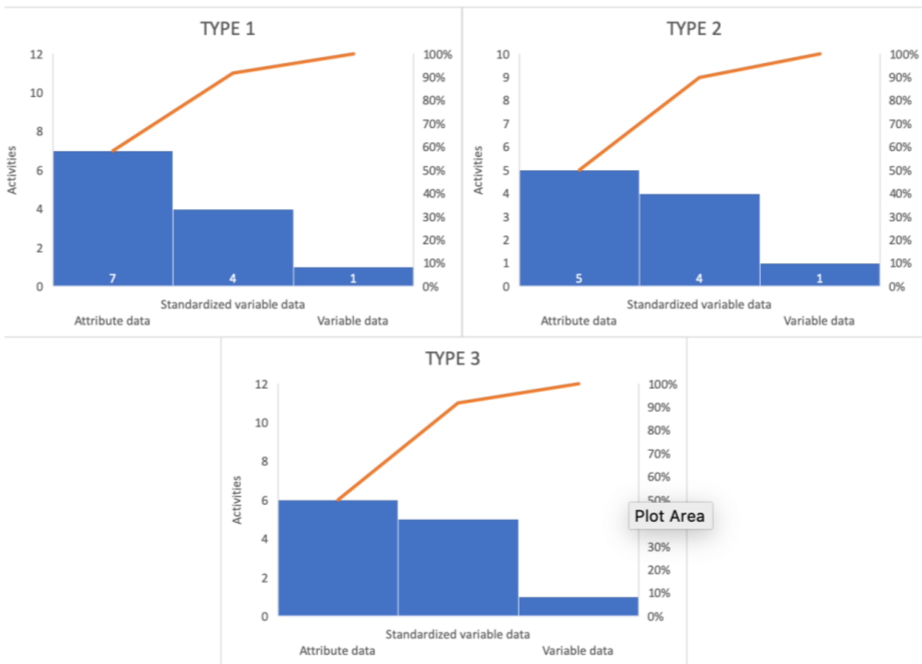


Figure 44: Distribution of activities in data categories for every packaging type

Source: Authors Figure

- M.S.A. – Measurement System Analysis

As mentioned in Chapter 4.2.3, conducting an M.S.A. helps us distinguish inconsistencies in measurements. Although most activities include attribute data outputs for every packaging type, as presented in Figure 38, our main focus lies on the activity with non-standardized variable data outputs.

While the case study department follows all the necessary standardizations (Operator's training and certification, Visual aids, etc.), the pallet wrapping should be tested to ensure the same results. The exact measurements are conducted multiple times to ensure that the same findings are produced every time. To increase the collected data's validity, we examined data from two different operator groups, and we took 15 measurements from each group. We confirmed there is no variation in the measurement system by completing the M.S.A., as presented in Figure 44.

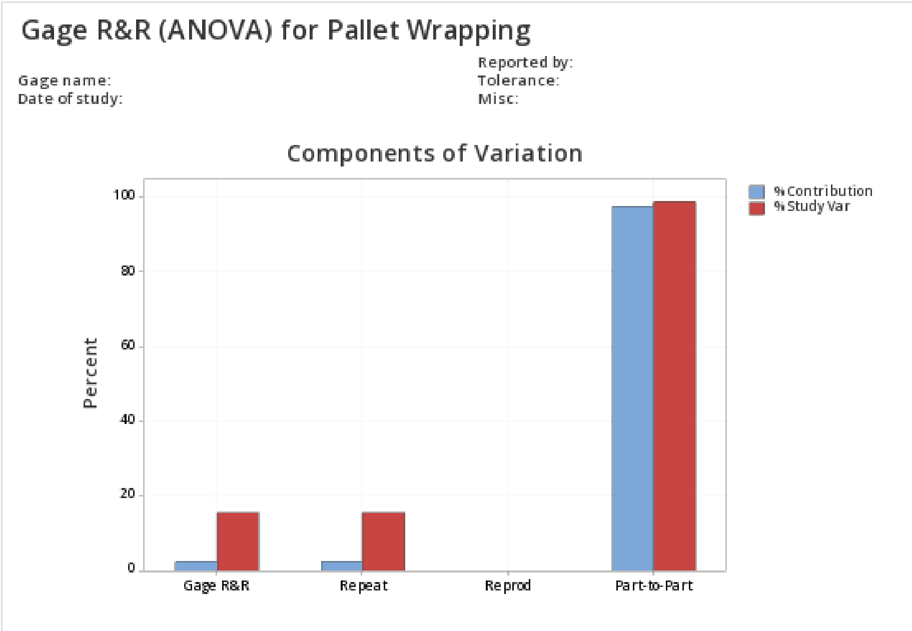


Figure 45: Measurement System Analysis

Source: Authors Figure

5.2.3 Analyze Phase

At the end of the Measure phase, all necessary information and data have been collected. In the Analyze phase, the main goal is to use these data to understand the defects in the current process in order to execute improvement tasks during the Improve phase. We examine whether there are possible sources of delays, material losses, and insufficient quality during the procedure's execution stages.

Below are some of the tools we used during the implementation of the Analyze phase. In the Analyze Phase we also focus on understanding the root cause of the problems we listed in the Makigami process map.

At the end of the Measure phase, all necessary information and data have been collected. In the Analyze phase, the main goal is to use these data to understand the defects in the current process in order to execute improvement tasks during the Improve phase. We examine whether there are possible sources of delays, material losses, and insufficient quality during the procedure's execution stages. Below are some of the tools we used during the implementation of the Analyze phase

- Muda Hunt Checklist

The main purpose of the L.S.S. method is to minimize waste. One tool used to detect waste processes is the Muda hunt checklist. Once the defects are detected during the execution of the process, it falls into one of the 7 MUDA categories (Overproduction, Waiting, Motion, Over-processing, Inventory, Transportation, Defects) and improvements are set to be implemented.

In particular, during the implementation of the project, at the Measure phase, two processes were identified, which led to material wastes:

- For the most preferred type of packaging (type 3), where four ties are made with paper tape, it was cut in larger quantities than needed, leading to additional consumption.

- Before the stage of wrapping the pallet, a plastic sheet is placed on top of the pallet in order to protect the product from water, moisture, etc. This process is not automated, and the user, based on experience, chooses to cut the plastic sheet in a longer length.

Pareto Chart

Based on the XY Matrix, which was implemented during the Measure phase, the Pareto diagram of the department's processes was created. Figure 46 presents the criticality of the sub-processes as defined in the XY Matrix, based on the measurements made.

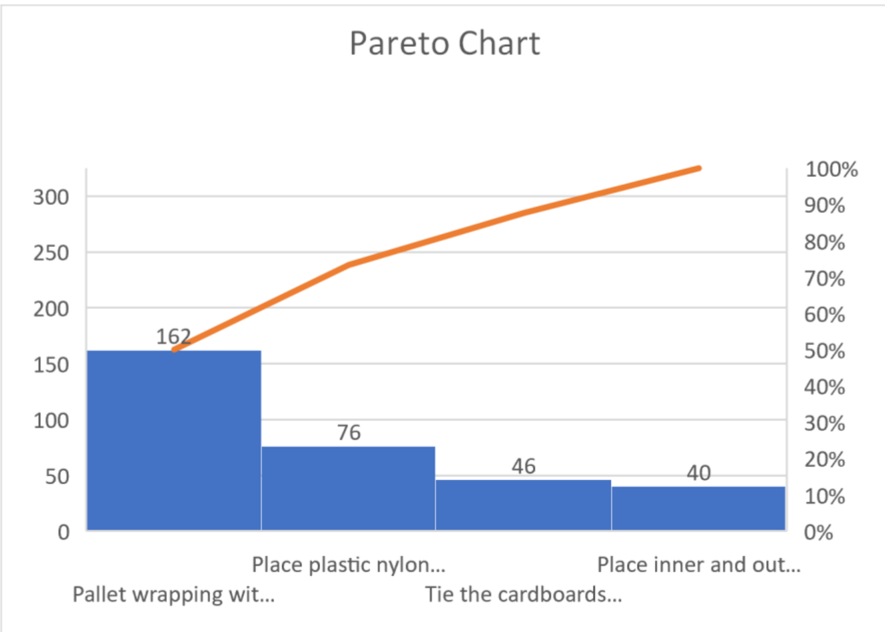


Figure 46: Pareto Chart (Crucial sub-processes)

Source: Authors Figure

Based on what we have mentioned, it is understood that the most critical process for the project is the "wrapping" of the pallet with plastic stretch film. In order to accurately calculate this procedure, different measurements were taken, depending on the different parameters affecting the consumption of Stretch Film, which are divided into the following categories:

1. Measurements (same pallet size - same type of packaging - same coil diameter - different pallet height)

2. Measurements (same pallet size - same type of packaging - different coil diameter - same pallet height)

3. Measurements (same pallet size - different type of packaging - same coil diameter - same pallet height)

4. Measurements (different pallet size - same type of packaging - different coil diameter - same pallet height)

In this way, it was calculated how much each parameter affects the final measurements, and a model for calculating the consumption of the plastic Stretch Film was determined, as the case may be.

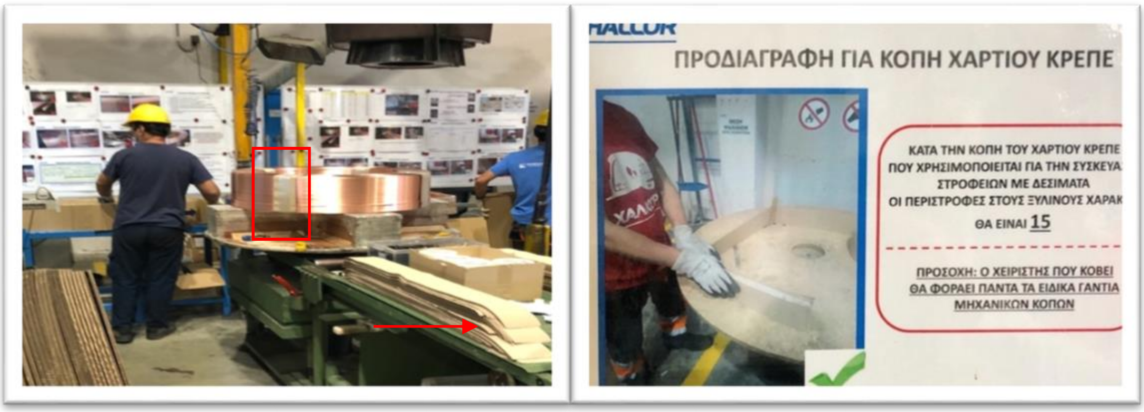
Finally, implementing these L.S.S. tools and methods, we came with innovative ideas to improve the current situation, as will be presented in the following phase.

5.2.4 Improve Phase

With the completion of the Measure and Analyze phases, the Improve phase follows. In this phase, the main goal is to improve the process by eliminating all possible sources of waste.

During the Analyze phase, we identified two sub-processes in which there is material waste:

- For packaging type 3, where four ties are made with paper tape, it was cut in larger quantities than needed, leading to additional consumption. A specific way of performing this sub-process was determined in order to greatly reduce the waste, taking into account the productivity of the operator. (Estimated benefit EUR 2,000 / year)



Picture 1: Standardization of the process

Source: Company’s Packaging Department

- The cutting of the plastic sheet according to specifications registered in SAP was at 2 meters, in contrast to the measurements taken (30 measurements), whose average value is 2.67 meters. For this reason, specific cutting lengths were determined, depending on the packaging needs, by optical means (Estimated benefit EUR 4,000 / year). Picture 2 shows the way in which this specification is temporarily defined.

Picture 2: Standardization of the process

Source: Company's Packaging Department

The project where the improved process was implemented concerns the final bill of materials per type of packaging. Indicatively, in Figure 47, the BOM demonstrated to the bottom left of the Excel sheet regards the packaging type 1.

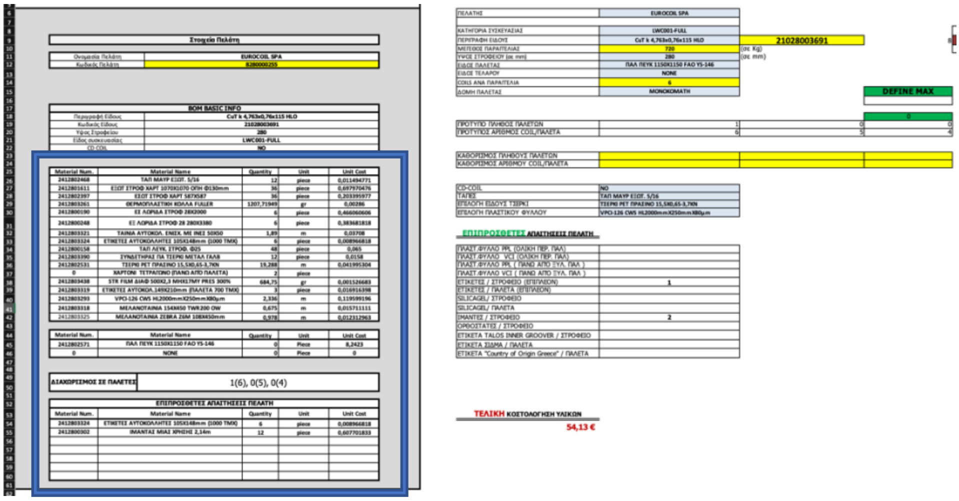


Figure 47: Updated B.O.M.

Source: Authors Figure

In the next Figure we present, how the BOM is defined and which parameters influence its final outcome. In the first cell we choose the customer from the drop-down list, that happens because the BOM depends on customer's requirements for specific packaging type. Next, we choose packaging type, and product category; we specify the height of the coil, define the total amount of the order, and choose the desired pallet of the customer. The coils per order will be calculated based on the dimensions of the product chosen by each customer as well as the size of the order.

Besides, the number of pallets will be calculated using the Microsoft Excel Solver aiming to the fewest possible pallets, or through loading specifications set by the customer. We choose type of coil (CD-Coil or not) pack and specify if plugs are needed. Through this procedure we define the exact BOM of the packaging process based on customer's requirements.

ΠΕΛΑΤΗΣ	EUROCOIL SPA		
ΚΑΤΗΓΟΡΙΑ ΣΥΣΚΕΥΑΣΙΑΣ	LWC001-FULL		
ΠΕΡΙΓΡΑΦΗ ΕΙΔΟΥΣ	CuT k 4,763x0,76x115 HLO	21028003691	
ΜΕΓΕΘΟΣ ΠΑΡΑΓΓΕΛΙΑΣ	720	(σε Kg)	
ΥΨΟΣ ΣΤΡΟΦΕΙΟΥ (σε mm)	280	(σε mm)	
ΕΙΔΟΣ ΠΑΛΕΤΑΣ	ΠΑΛ ΠΕΥΚ 1150X1150 FAO YS-146		
ΕΙΔΟΣ ΤΕΛΑΡΟΥ	NONE		
COILS ANA ΠΑΡΑΓΓΕΛΙΑ	6		
ΔΟΜΗ ΠΑΛΕΤΑΣ	ΜΟΝΟΚΟΜΑΤΗ		DEFINE MAX
			0
ΠΡΟΤΥΠΟ ΠΛΗΘΟΣ ΠΑΛΕΤΩΝ	1	0	
ΠΡΟΤΥΠΟΣ ΑΡΙΘΜΟΣ COIL/ΠΑΛΕΤΑ	6	5	
ΚΑΘΟΡΙΣΜΟΣ ΠΛΗΘΟΥΣ ΠΑΛΕΤΩΝ			
ΚΑΘΟΡΙΣΜΟΣ ΑΡΙΘΜΟΥ COIL/ΠΑΛΕΤΑ			

CD-COIL	NO
ΤΑΠΕΣ	ΤΑΠ ΜΑΥΡ ΕΞΩΤ. 5/16
ΕΠΙΛΟΓΗ ΕΙΔΟΥΣ ΤΣΕΡΚΙ	ΤΣΕΡΚΙ PET ΠΡΑΣΙΝΟ 15,5X0,65-3,7KN
ΕΠΙΛΟΓΗ ΠΛΑΣΤΙΚΟΥ ΦΥΛΛΟΥ	VPCI-126 CWS HL2000mmX250mmX80μm

ΕΠΙΠΡΟΣΘΕΤΕΣ ΑΠΑΙΤΗΣΕΙΣ ΠΕΛΑΤΗ

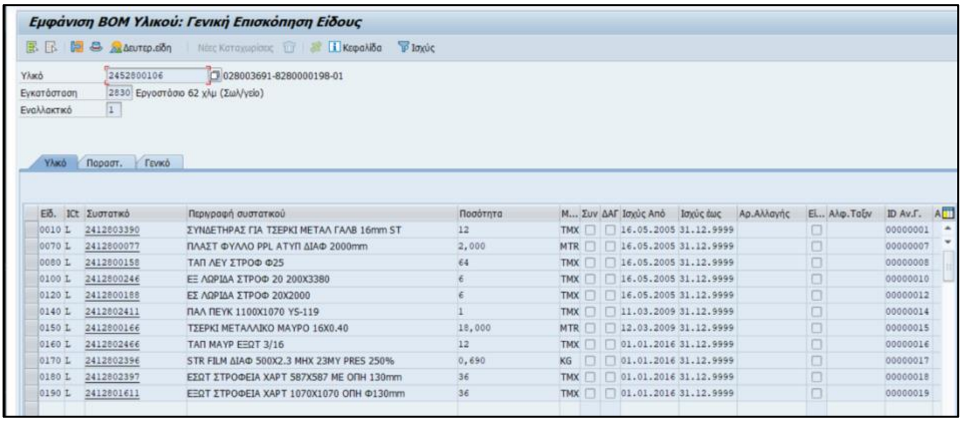
ΠΛΑΣΤ.ΦΥΛΛΟ PPL (ΟΛΙΚΗ ΠΕΡ. ΠΑΛ)	
ΠΛΑΣΤ.ΦΥΛΛΟ VCI (ΟΛΙΚΗ ΠΕΡ. ΠΑΛ)	
ΠΛΑΣΤ.ΦΥΛΛΟ PPL (ΠΑΝΩ ΑΠΟ ΞΥΛ. ΠΑΛ)	
ΠΛΑΣΤ.ΦΥΛΛΟ VCI (ΠΑΝΩ ΑΠΟ ΞΥΛ. ΠΑΛ)	
ΕΤΙΚΕΤΕΣ / ΣΤΡΟΦΕΙΟ (ΕΠΙΠΛΕΟΝ)	1
ΕΤΙΚΕΤΕΣ / ΠΑΛΕΤΑ (ΕΠΙΠΛΕΟΝ)	
SILICAGEL/ ΣΤΡΟΦΕΙΟ	
SILICAGEL/ ΠΑΛΕΤΑ	
ΙΜΑΝΤΕΣ / ΣΤΡΟΦΕΙΟ	2
ΟΡΘΟΣΤΑΤΕΣ / ΣΤΡΟΦΕΙΟ	
ΕΤΙΚΕΤΑ TALOS INNER GROOVER / ΣΤΡΟΦΕΙΟ	
ΕΤΙΚΕΤΑ ΣΙΔΜΑ / ΠΑΛΕΤΑ	
ΕΤΙΚΕΤΑ "Country of Origin Greece" / ΠΑΛΕΤΑ	

Figure 48: Parameters that influence B.O.M.

Source: Authors Figure

Finally, in order to prove that the improvement project was successfully completed, Figure 49,50 show a comparison of the B.O.M. that we drew from the sap and concerns the previous situation with the new, improved B.O.M. The result is obvious as in the BOM that exists in SAP, and some materials are not included while the quantities of those that exist in some cases are wrong.

The comparison concerns the same product, same requirements of packaging as well as the same order quantity. In particular, a packaging type (full packing) was selected for a pallet with six coils where the height of each coil is 200mm.



Εμφάνιση BOM Υλικού: Γενική Επισκόπηση Είδους

Δευτερ.είδη | Νέες Καταχωρίσεις | Κεφαλίδα | Ισχύς

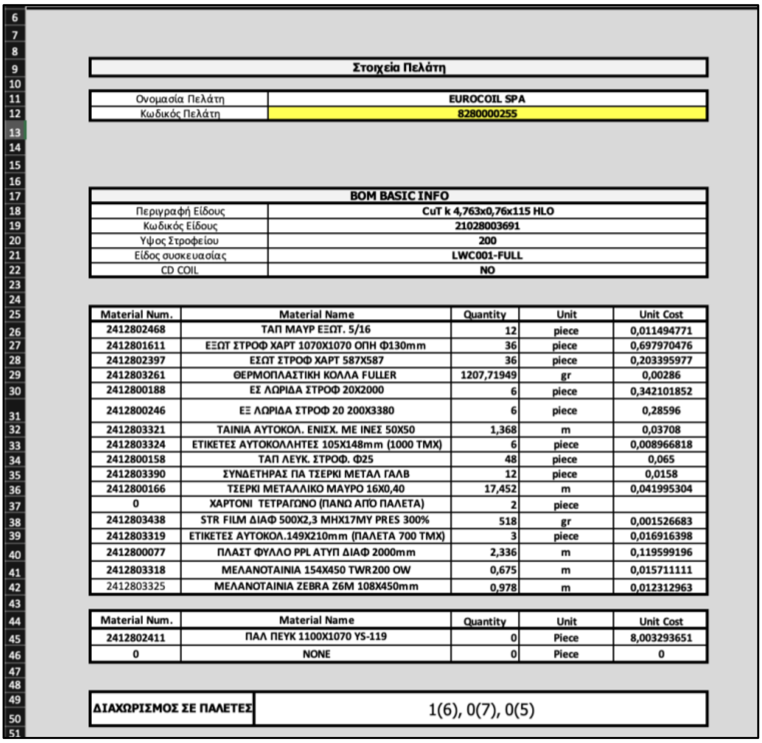
Υλικό 2452800106 028003691-8280000198-01
Εγκατάσταση 2830 Εργοστάσιο 62 χλμ (Σωλ/γείο)
Εναλλακτικό 1

Υλικό | Παραστ. | Γενικό

Είδ.	ICt	Συστατικό	Περιγραφή συστατικού	Ποσότητα	Μ...	Συν	ΔΑΓ	Ισχύς Από	Ισχύς έως	Αρ.Αλλαγής	Ει...	Αλφ.Ταξν	ID Αν.Γ.
0010	L	2412803390	ΣΥΝΔΕΤΗΡΑΣ ΓΙΑ ΤΣΕΡΚΙ ΜΕΤΑΛ ΓΑΛΒ 16mm ST	12	TMX			16.05.2005	31.12.9999				00000001
0070	L	2412800077	ΠΛΑΣΤ ΦΥΛΛΟ PPL ΑΤΥΠ ΔΙΑΦ 2000mm	2,000	MTR			16.05.2005	31.12.9999				00000007
0080	L	2412800158	ΤΑΠ ΛΕΥ ΣΤΡΟΦ Φ25	64	TMX			16.05.2005	31.12.9999				00000008
0100	L	2412800246	ΕΞ ΛΩΡΙΔΑ ΣΤΡΟΦ 20 200X3380	6	TMX			16.05.2005	31.12.9999				00000010
0120	L	2412800188	ΕΣ ΛΩΡΙΔΑ ΣΤΡΟΦ 20X2000	6	TMX			16.05.2005	31.12.9999				00000012
0140	L	2412802411	ΠΑΛ ΠΕΥΚ 1100X1070 YS-119	1	TMX			11.03.2009	31.12.9999				00000014
0150	L	2412800166	ΤΣΕΡΚΙ ΜΕΤΑΛΛΙΚΟ ΜΑΥΡΟ 16X0.40	18,000	MTR			12.03.2009	31.12.9999				00000015
0160	L	2412802466	ΤΑΠ ΜΑΥΡ ΕΞΩΤ 3/16	12	TMX			01.01.2016	31.12.9999				00000016
0170	L	2412802396	STR FILM ΔΙΑΦ 500X2.3 MHX 23MY PRES 250%	0,690	KG			01.01.2016	31.12.9999				00000017
0180	L	2412802397	ΕΣΩΤ ΣΤΡΟΦΕΙΑ ΧΑΡΤ 587X587 ΜΕ ΟΠΗ 130mm	36	TMX			01.01.2016	31.12.9999				00000018
0190	L	2412801611	ΕΞΩΤ ΣΤΡΟΦΕΙΑ ΧΑΡΤ 1070X1070 ΟΠΗ Φ130mm	36	TMX			01.01.2016	31.12.9999				00000019

Figure 49: B.O.M. in company's SAP

Source: Company's SAP



Στοιχεία Πελάτη	
Ονομασία Πελάτη	EUROCOIL SPA
Κωδικός Πελάτη	8280000255

BOM BASIC INFO	
Περιγραφή Είδους	CuT k 4,763x0,76x115 HLO
Κωδικός Είδους	21028003691
Υψος Στροφείου	200
Είδος συσκευασίας	LWC001-FULL
CD COIL	NO

Material Num.	Material Name	Quantity	Unit	Unit Cost
2412802468	ΤΑΠ ΜΑΥΡ ΕΞΩΤ. 5/16	12	piece	0,011494771
2412801611	ΕΞΩΤ ΣΤΡΟΦ ΧΑΡΤ 1070X1070 ΟΠΗ Φ130mm	36	piece	0,697970476
2412802397	ΕΣΩΤ ΣΤΡΟΦ ΧΑΡΤ 587X587	36	piece	0,203395977
2412803261	ΘΕΡΜΟΠΛΑΣΤΙΚΗ ΚΟΛΛΑ FULLER	1207,71949	gr	0,00286
2412800188	ΕΣ ΛΩΡΙΔΑ ΣΤΡΟΦ 20X2000	6	piece	0,342101852
2412800246	ΕΞ ΛΩΡΙΔΑ ΣΤΡΟΦ 20 200X3380	6	piece	0,28596
2412803321	ΤΑΙΝΙΑ ΑΥΤΟΚΟΛ. ΕΝΙΣΧ. ΜΕ ΙΝΕΣ 50X50	1,368	m	0,03708
2412803324	ΕΤΙΚΕΤΕΣ ΑΥΤΟΚΟΛΛΗΤΕΣ 105X148mm (1000 TMX)	6	piece	0,008966818
2412800158	ΤΑΠ ΛΕΥΚ. ΣΤΡΟΦ. Φ25	48	piece	0,065
2412803390	ΣΥΝΔΕΤΗΡΑΣ ΠΑ ΤΣΕΡΚΙ ΜΕΤΑΛ ΓΑΛΒ	12	piece	0,0158
2412800166	ΤΣΕΡΚΙ ΜΕΤΑΛΛΙΚΟ ΜΑΥΡΟ 16X0,40	17,452	m	0,041995304
0	ΧΑΡΤΟΝΙ ΤΕΤΡΑΓΩΝΟ (ΠΑΝΩ ΑΠΌ ΠΑΛΕΤΑ)	2	piece	
2412803438	STR FILM ΔΙΑΦ 500X2,3 MHX17MY PRES 300%	518	gr	0,001526683
2412803319	ΕΤΙΚΕΤΕΣ ΑΥΤΟΚΟΛ.149X210mm (ΠΑΛΕΤΑ 700 TMX)	3	piece	0,016916398
2412800077	ΠΛΑΣΤ ΦΥΛΛΟ PPL ΑΤΥΠ ΔΙΑΦ 2000mm	2,336	m	0,119599196
2412803318	ΜΕΛΑΝΟΤΑΙΝΙΑ 154X450 TWR200 OW	0,675	m	0,015711111
2412803325	ΜΕΛΑΝΟΤΑΙΝΙΑ ZEBRA Z6M 108X450mm	0,978	m	0,012312963

Material Num.	Material Name	Quantity	Unit	Unit Cost
2412802411	ΠΑΛ ΠΕΥΚ 1100X1070 YS-119	0	Piece	8,003293651
0	NONE	0	Piece	0

ΔΙΑΧΩΡΙΣΜΟΣ ΣΕ ΠΑΛΕΤΕΣ	1(6), 0(7), 0(5)

Figure 50: The improved B.O.M.

Source: Authors Figure

Table 8 shows all the differences between the previous BOM and the new one.

	Improved BOM	BOM in SAP	
Material Name	Quantity		Unit
ΤΑΠ ΜΑΥΡ ΕΞΩΤ. 5/16	12	12	piece
ΕΞΩΤ ΣΤΡΟΦ ΧΑΡΤ 1070X1070 ΟΠΗ Φ130mm	36	36	piece
ΕΣΩΤ ΣΤΡΟΦ ΧΑΡΤ 587X587	36	36	piece
ΘΕΡΜΟΠΛΑΣΤΙΚΗ ΚΟΛΛΑ FULLER	1207,719489	-	gr
ΕΣ ΛΩΡΙΔΑ ΣΤΡΟΦ 20X2000	6	6	piece
ΕΞ ΛΩΡΙΔΑ ΣΤΡΟΦ 20 200X3380	6	6	piece
ΤΑΙΝΙΑ ΑΥΤΟΚΟΛ. ΕΝΙΣΧ. ΜΕ ΙΝΕΣ 50X50	1,368	-	m
ΕΤΙΚΕΤΕΣ ΑΥΤΟΚΟΛΛΗΤΕΣ 105X148mm (1000 TMX)	6	-	piece
ΤΑΠ ΛΕΥΚ. ΣΤΡΟΦ. Φ25	48	64	piece
ΣΥΝΔΕΤΗΡΑΣ ΓΙΑ ΤΣΕΡΚΙ ΜΕΤΑΛ ΓΑΛΒ	12	12	piece
ΤΣΕΡΚΙ ΜΕΤΑΛΛΙΚΟ ΜΑΥΡΟ 16X0,40	17,452	18	m
ΧΑΡΤΟΝΙ ΤΕΤΡΑΓΩΝΟ (ΠΑΝΩ ΑΠΌ ΠΑΛΕΤΑ)	2	-	piece
STR FILM ΔΙΑΦ 500X2,3 MHX17MY PRES 300%	518	690	gr
ΕΤΙΚΕΤΕΣ ΑΥΤΟΚΟΛ.149X210mm (ΠΑΛΕΤΑ 700 TMX)	3	-	piece
VPCI-126 CWS HL2000mmX250mmX80μm	2,336	2	m
ΜΕΛΑΝΟΤΑΙΝΙΑ 154X450 TWR200 OW	0,675	-	m
ΜΕΛΑΝΟΤΑΙΝΙΑ ZEBRA Z6M 108X450mm	0,978	-	m
ΠΑΛ ΠΕΥΚ 1100X1070 YS-119	1	1	piece

Table 12: Comparison between past and present B.O.M.

Source: Authors Figure

5.2.5 Control Phase

The end of the Improve phase follows the Control phase, where the process is evaluated and whether it is within the requirements set by the customer. Once the appropriate modifications to the process have been completed, the "leader" of the project (Black Belt, LSS Definition) is called upon to review the results' validity. Some tools used to perform this step are Control Charts, Bar Charts, Statistical Process Control, etc. This stage is expected to be completed in the coming months by the project managers and is the final stage of implementing the DMAIC methodology.

6 Conclusion

In order for a company to be globally competitive, it is particularly important to listen to the trends prevailing in the sector in which it operates, to examine technologies, and apply those that best meet its needs.

In this dissertation, we described and applied one of the leading methods of continuous improvement, Lean Six Sigma. In the beginning, we presented the theoretical background of the Lean and Six Sigma methods and their combination. The main goal of every improvement project is that after its implementation, tangible results will emerge for the company.

The research was followed by the theoretical background of the DMAIC methodology as well as the methods and tools used during the implementation of the project, which concerns the updating of the bill of materials of the packaging process while at the same time aiming to reduce waste of materials in the sub-processes is sought.

During the application of the DMAIC methodology, in the Define phase, the requirements of the internal customers were determined, which became goals during the Measure and Analyze phases. In the Improve phase, elimination of waste is sought in two sub-processes from which an economic benefit was extracted. Finally, the Control phase is not listed in the study as it will be executed by the person in charge of the project, together with the project of integration of the new updated BOM in SAP.

6.1 Lessons learned in the improvement project

Implementing the DMAIC methodology us understand how the Project team is formed, the hierarchy and the interaction between the members, and the way the decisions are made at each phase of the project.

Equally important with the "technical" characteristics of the project plays the behavior of members within a team. Through meetings with department executives, meetings between all members involved in the project, and through daily communication with the production engineer, important information was extracted. Observe how professionals behave on a daily basis in their work, how they act as members of a team, the communication channels they have established in order to communicate more effectively, as well as the way they organize their time in order to achieve their goals.

Finally, another important benefit was the "living" experience of the industry. The work environment, the experiences in a large industry, the development prospects, as well as the jobs with the greatest interest were evaluated.

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