Six Sigma & Lean Six Sigma

Handbook

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1. Introduction:

Bill Smith (1929-1993), When he was Motorola's Vice President and Senior Quality Manager in the late 1980s, "Father of Six Sigma" introduced the Six Sigma approach for organizational development. Using six sigma to enhance customer connections and create organizational success has been widely adopted since Motorola saw the billions of dollars in savings and improvements that came as a result of implementing the strategy. Jack Welch started Six Sigma at GE in 1996, when he was Chairman of the Board and CEO of the company. The accomplishments obtained have led to an evolution or possibly a revolution in the implementation of the Six Sigma principles and ideas. In recent years, there has been a lot of interest in Six Sigma methodologies and how they may be used to speed up process improvement. Organizational executives have read and heard about the financial gains that some top Six Sigma supporters have realized and are eager to emulate this degree of success inside their organizations. Ten years ago, the term "Six Sigma" was unknown to most individuals. Today, a search for 'Six Sigma' on the Internet will return hundreds of thousands of 'hits.' People with knowledge and skill in Six Sigma can find hundreds of work possibilities if they do a job search in this field. Six Sigma advertising may be seen in abundance in quality publications. Despite this, many individuals are still unfamiliar with the definition of Six Sigma or if it provides anything unique in comparison to other methods. Many of the firms that utilize Six Sigma today previously achieved gains via the use of Total Quality Management (TQM), Crosby's Zero Defects (ZD), or Quality Circles (QC), but these programs clearly did not meet all of their requirements. If this were not the case, these same organizations would not be investing extra time and money on Six Sigma implementation.

Six Sigma is defined as a process with a maximum mistake rate of 3.4 per million possibilities. When it was included in the 1.5 sigma shift and the varying sensitivity to process complexity, this might be perplexing for the uninitiated. For those who lack a basic understanding of statistics or who haven't had official Six Sigma training, the more difficult it becomes to grasp the concepts of Six Sigma. (Walters, 2005). The most recent advancement is the incorporation of SixSigma into the creation of new products. This is because the firm may save a lot of money if it incorporates these features into new products and services throughout the design process.. It has been claimed that "70-80% of all quality issues are design related and not manufacturing induced" by a global consultancy called Lean Sigma Technologies, LLC It's possible to avoid expensive quality difficulties by addressing these issues throughout the design phase. Six-basic Sigma's tenet is that the quality of products and processes may be greatly enhanced by gaining a better grasp of the connections between the various inputs and the various quality indicators. The notion of the "voice of the client" is essential to these partnerships. Only the client who will benefit from a product or procedure can determine the quality of its results. The truth is that Six-Sigma can be implemented to decrease process flaws and variability in both manufacturing and businesses. Among other things, it may be used to boost delivery timeliness, decrease cycle times for recruiting and training new personnel, enhance logistics, boost sales forecasting, and enhance customer service quality.

2. What is Six Sigma (6σ)?

Six Sigma is a process improvement methodology that gives companies the tools they need to boost the efficiency of their company operations. Defect reduction, improved revenues, staff morale, and product or service quality are all a result of this rise in performance and decrease in process variance (asq.org, *What is* 6σ*?*). Six Sigma as a technique for process improvement necessitates the use of many tools and expertise. Six sigma defines the statistical notion

represented by 6σ, which stands for probability. (*Six sigma: A complete step-by-step guide* 2018). To explain it in the simplest terms possible, Six Sigma (6σ) is a statistical depiction of what many industry professionals refer to as a "perfect" process. The 3.4 flaws that are found for every million opportunities in a Six Sigma process is a very low rate when measured against industry standards. This indicates that 99.99966 percent of the items created utilizing a Six Sigma methodology do not include any flaws. When procedures are accurate to one sigma below-5a, which is equivalent to 99.97%, there are 233 mistakes for every million chances. To put it another way, the proportion of dissatisfied consumers will increase significantly.
Practical methods, skills, means, or procedures, such as tools and techniques, may be used to specific activities to promote progress and development. (Spring et al., 1998)
Using the equation that is provided below, businesses and groups of people may determine the sigma level of a product or process:

$$\left(\frac{(\#\,of\ opportuninties - \#\,of\ defects)}{\#\,of\ opportunities}\right) \times 100 = Yield$$

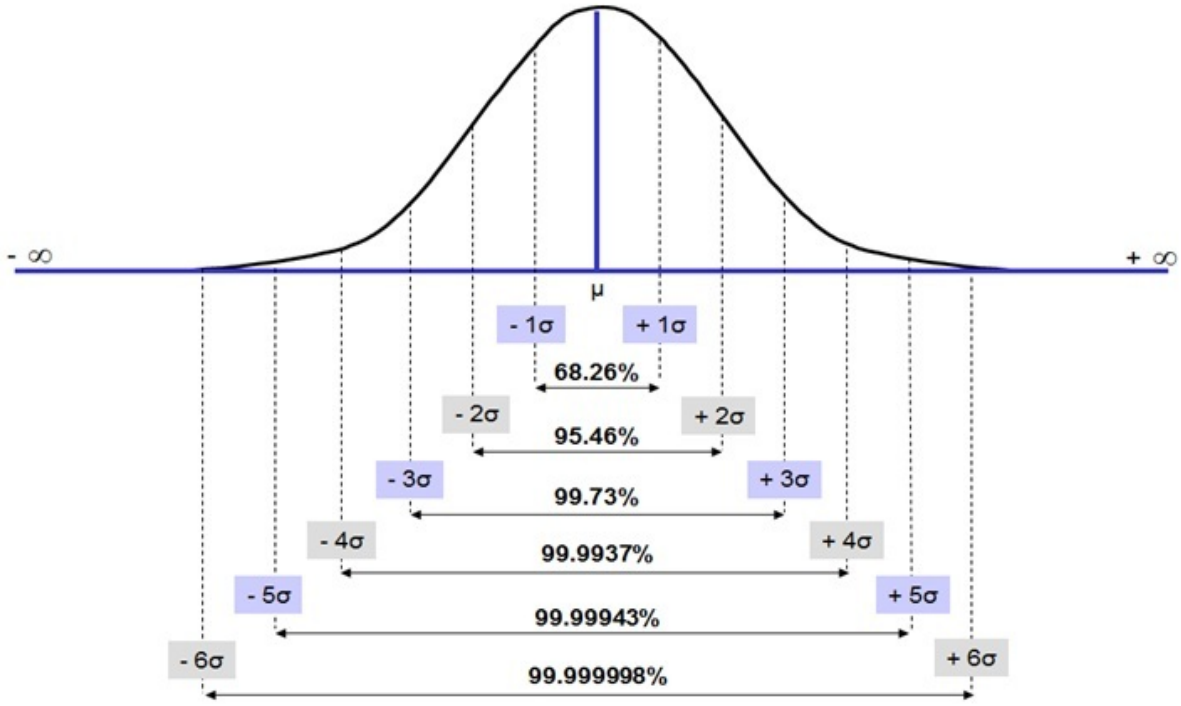
Source: (*Six sigma: A complete step-by-step guide* 2018)

“Determine the capability of the process by counting the number of defects that occur in each opportunity. The acceptable number to achieve six sigma is 3.4 Defects Per Million Opportunities (DPMO).

Unit – the item produced or processed or created.
Defect – anything that causes a failure (i.e. misses the customer’s requirements.)
Opportunity refers to the amount of quality measures that are absolutely essential for us to depend on for each potential instance of a defect. This number is equal to 4 if there are four distinct kinds of flaws. DPO = Defects/(Units * Opportunity)
DPMO =(Defects / Units * Opportunities) * Total 1,000,000
Yield = 1-DPO (It refers to the capability of the process to generate units, that are free of defects. Find out if you need to have zero flaws or whether there is partial credit available.)

If the process is only considered correct if there are no defects at all (100% correct), then use the DPMU calculation (defects per million units) DPMU = (Defects / Units) * 1,000,000
If partial credit is received for meeting some of the requirements: use the DPMO calculation (defects per million opportunities) DPMO = (Defects / Units * Opportunities) * Total 1,000,000” (Hessing et al., 2021)

Figure 1: Six Sigma Normal Distribution



Source: (*Six Sigma DMAIC Process - Measure Phase - Measurement System* https://www.sixsigma-institute.org/sixsigma_images/six_sigma_normal_distribution_2.jpg)

Reduced variability across the board is one of the primary goals of the Six Sigma business strategy, which has a substantial positive impact on both customer happiness and shareholder profitability. This is way companies implement Six Sigma. Six Sigma improves the capacity to provide customer satisfaction and cost efficiency outcomes in months rather than years, and to maintain the pace of progress or exceed it. Simply for every dollar the company spend on Six Sigma projects it will bring $4 of savings to its bottom line.
Three Sigma is the historical standard 93.32% perfection four Sigma is the current standard of 99.38% perfection Six Sigma the future standard is 99.9997% perfection or 3.4 errors per million transactional opportunities. Three Sigma is not quite good enough well. Let's assume, 20,000 last articles of mail per hour, 15 minutes of unsafe drinking water each day, 5000 incorrect surgical operations per week, 2 short or long landings at the major airports each day, 200,000 wrong drug prescriptions each year, no electricity for almost 7 hours each month 40,500 newborn babies dropped each year by precise use of Six Sigma quality, or 99.9997% perfection yields only one incorrect drug prescription every 25 years only 3 newborn babies dropped each century. Many high technology companies are operating at 4 Sigma which is 99.4% accuracy and translates to 6000 defects per one million opportunities. As the Sigma level increases cost and cycle time go down while customer satisfaction goes up. The perfection or accuracy of each Sigma level are written in Table 1 below.

Table 1: Sigma Performance Table

Sigma Performance Levels – One to Six Sigma		
Sigma Level	**Defects (or Errors) Per Million Opportunities (DPMO)**	**Yield (or Produced or Delivered) Correctly (%)**
1	691,462	30.85
2	308,538	69.146
3	66,807	93.319
4	6,210	99.379
5	233	99.9767
6	3.4	99.9997

Source: (Terry, *Sigma performance levels - one to Six sigma* 2019)

Six-Sigma is comprised of two essential components, namely the COPQ and the CTQ (continuous improvement process). The cost of poor quality (COPQ) is represented by the letter C, whereas the crucial to quality (CTQ) is represented by the letter T. The goal of the COPQ is to incorporate all expenses associated with all activities at all management levels, as well as the visible costs associated with those activities. COPQ is computed by recognizing all of the expenses incurred during management operations in a quantifiable way and devising a strategy for reducing those costs.
CTQ, which stands for vital to quality, is the second important factor to consider. When using COPQ, the organization can see the overall cost, which includes both apparent and hidden expenditures. The identification of CTQ variables is required before any savings may be realized. The CTQ variables are the most important parameters that influence the quality of the target for the system's target quality evaluation.
Knowing that the purpose of Six-Sigma is to reduce the COPQ by using the CTQ variables, we may proceed. It is necessary to define the fundamental notion of Six-Sigma as a mathematical programming model, as indicated in the diagram below, to comprehend it fully:

Minimize COPQ
S.t.

$f(CTQ_1, CTQ_{2,\ldots..}, CTQ_n) = 0 \quad (2)$

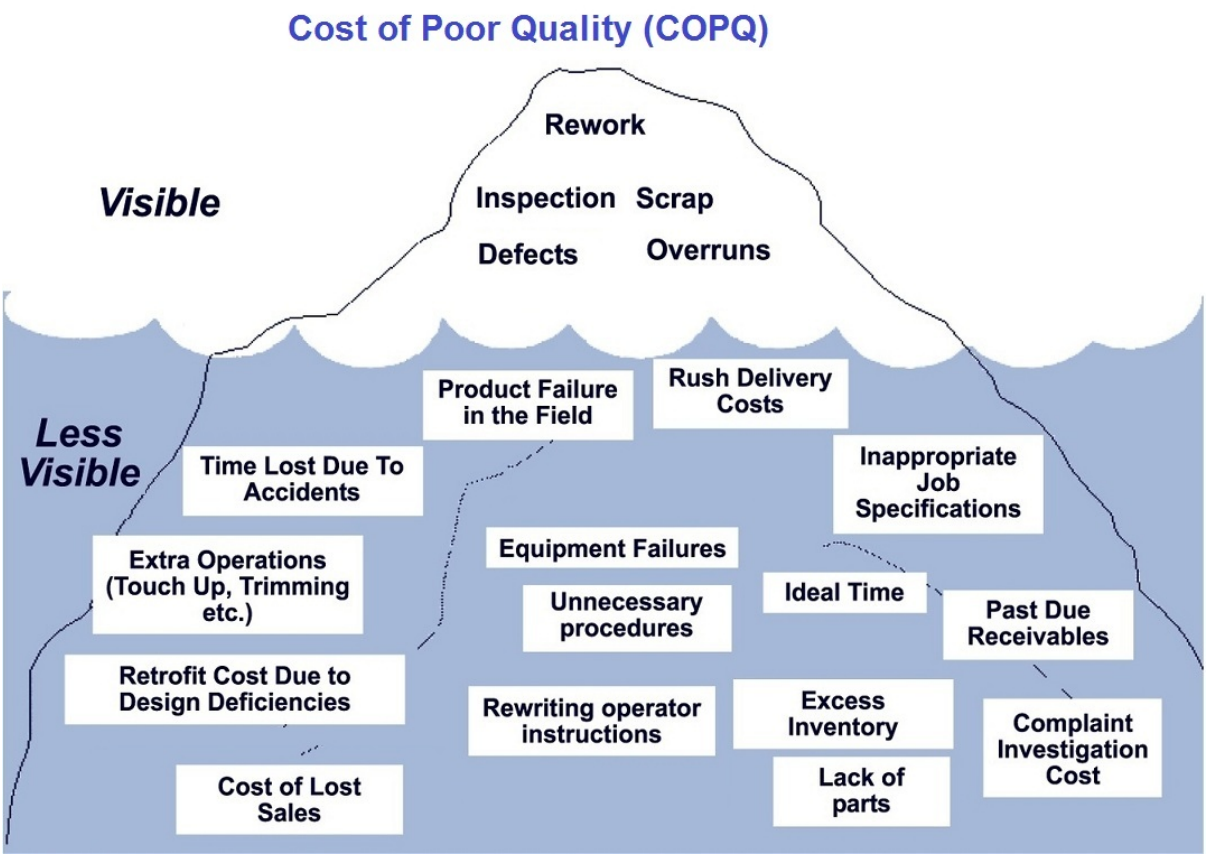
$g(CTQ_1, \ldots, CTQ_n, X_1, X_2, \ldots X_n) \leq 0$

Source: (Zare Mehrjerdi, *Six-Sigma: Methodology, tools and its future* 2011)

Determine the time period being evaluated—this will help to focus the data's scope. Then increase the overall waste / variance by the time spent resolving a problem. The result value should represent the business's expense of low quality.

COPQ = (Waste (materials) + defects (variation occurence))* inefficiencies (time spent fixing)

Figure 2: Cost of poor quality (COPQ)



Source: (*Cost of poor quality – COPQ* 2014 https://bizdiagram.com/cost-of-poor-quality-copq/)

3. History of Six Sigma and its application in both product and service sector

According to Navin Shamji Dedhia in 2005 for the most part, Six Sigma has saved businesses billions of dollars by helping them identify and eliminate issues before they become large-scale crises. Companies like Motorola, American Express, Ford Motor Company, and Allied Signal have all used six sigma principles in their operations in an ambitious manner. According to the findings of corporations who have implemented a six-sigma project in their organizations:

i. The patent application took Motorola Legal Department two years to complete. Bob Galvin wanted the patent department to seek out a way to reduce the time it took to file a patent application to fewer than 90 days. The patent department used six sigma tools to cut the time in half, with the lowest period being 17 days. Motorola saved $1.5 billion over the course of 11 years.
ii. The cost of submitting a Japanese patent application has been decreased from $48,000 to $1200 per application.
iii. GE expanded its use of communication satellites from 63 percent to 97 percent, generating an extra $1.3 million in income per year. GE adapted Motorola's Six Sigma concept to a project-based approach that was supported by the company's upper management. In 1999, GE saved $2 billion.
iv. For continuous improvement operations, the Ames Rubber Corporation (winner of the Malcolm Baldrige National Quality Award in the Small Business Category in 1993) employs the Baldrige criteria, ISO 9000 Quality Management System, and six sigma techniques.

v. With the support of Raytheon Corporation on measures to pre-screen scientists before to engaging them, the National Science Foundation was able to reduce ill individuals evacuation from Antarctica by 22%.
vi. The six sigma technique was applied to eliminate prescription mistakes at a hospital in Milwaukee, Wisconsin.
vii. For innovation, efficiency, and quality, Samsung Electronics Co. (SEC) in Seoul, Korea, use the six sigma technique. During the years 2000 and 2001, the SEC completed 3,290 six-sigma projects.
viii. American Express enhanced the efficiency of their plastic issuing procedures by using six sigma methodological approaches.
ix. DuPont adopted six sigma approaches to reduce the time it took to process long-term disability benefits applications.
x. Using the six sigma innovation, the city of Fort Wayne, Indiana, was able to repair 98% of its potholes in only one day.
xi. Defense contractors were among the first to use six sigma (Ex: Northrop Grumman, etc.)

xii. Government officials in the United States are considering using six sigma to combat the "war on terrorism" (Homeland Security Project).

An average of $100,000 to $200,000 is saved each improvement project that is performed. When a company has achieved success, it has spent a significant amount of money in training and resources, as well as involving many people.

4. Six Sigma methodologies

The first thing to consider is from whence does the power of Six-Sigma originate. It should go without saying that its enormous strength resides in its "empirical," data-driven approach, as well as the fact that it focuses on employing quantitative measurements of how the system is functioning in terms of attaining the aim of process improvement and variation reduction. Collaborative efforts are a crucial and critical aspect of the Six-Sigma process, and they will assist management in gaining constructive feedback from employees. T A project team is often made up of people who oversee the project. There are individuals such as consumers, administrative colleagues, and suppliers who need to be recognized and directed to concentrate on a certain issue or problem.

4.1. DMAIC: The DMAIC technique is used for existing goods and processes. In situations when the root cause of a problem is unclear, considerable cost savings may be realized, and the project can be completed in 4-6 months, the DMAIC Six-Sigma technique is the best option (Breyfogle et al., 2001). For this instance, there are five measures to take into consideration. The process begins with

- Define:
  - Identifying the target customers and determining their needs
  - Find out what the consumer cares about most.
- Measure:
  - Identify and categorize critical input and output properties, as well as validate measurement systems
  - Gather information and create a baseline of performance.
- Analyze:
  - To get a better understanding of the process, analyze raw data and turn it into information.
- Improve:

        - Investigate ways to increase process capabilities and evaluate the outcomes in relation to the starting point.
    - Control:
        - Keep a track on the procedure to ensure that no unexpected changes take place.

Source: (Murman et al., 2012 MIT)

For example, a car company wants improvement in the cars manufactured each day and improve the quality of production with efficiency also considering the customer compliments. In the define stage, the company looks for what are the customer requires and the process as a whole and determine the issues with the manufacturing process in this case finding out why the cars have varying windshield wiper quality and how to optimize the current process to manufacture more cars.
In the measure phase the company determine how the process is performing currently and it's an altered state determined by the current number of cars that are manufactured in the day. Let's assume in the current scenario 100 cars are manufactured in a day and each of these cars are outfitted with a pair of windshield wipers by 30 machines and one of them is faulty.
Using some of the metrics measured or how many cars are produced in a day, time taken to assemble a car, how many windshield wipers were attached in a day, time that takes them to do so defects detected from each machine on assembly completion and so on following this in the analyze phase, the company determine what caused the defect or variation on analyzing previous data they find out that one of the machines that installed the windshield wiper was not performing, as well as it was supposed to production was taking longer. When transporting the car chassis between different locations, it took longer because cranes had to individually pick and drop the frame; this was due to the fact that the wheels were only attached to the car during the final stage.
Next, in an improved phase, the company makes changes to the manufacturing process to ensure defects are addressed; the company replace the faulty machines that installed the windshield wiper. With another one they also find a way to save time by attaching wheels on the frame in the initial stages of the manufacturing process unlike elder was done earlier now. The car can be moved across the assembly area faster and finally in the control phase they make regular adjustments to control new processes and future performance based on the changes made. The company was able to reduce production time and manufacture about 200 cars a day with a higher quality of output.
DMAIC is one of the most widely utilized approaches in the world, and it focuses on enhancing the organization's current product and services.

4.2. DMADV: The DMADV method is used to design new products and processes.In addition, there are five processes in this case: Define—Measure—Analyze—Design—Verify. (Zare Mehrjerdi, 2011)

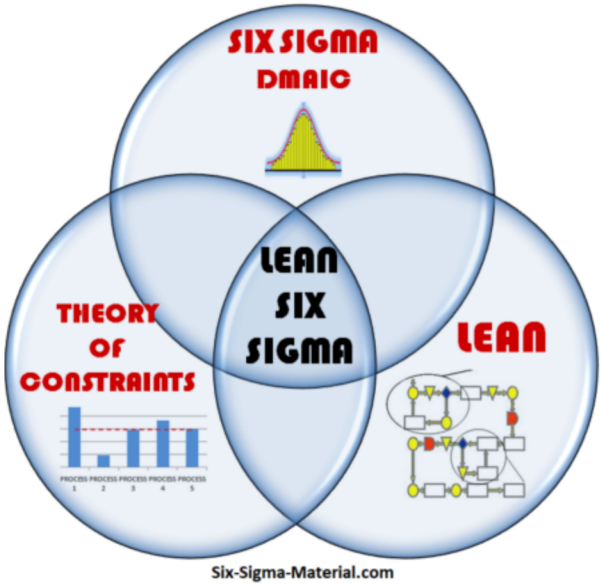
The second methodology is DMADV which is short for define measure analyze design and verify it is used when the company has to create a new product or service from scratch it is also called DFSS or design for six Sigma. For example, a company decides to build a new model of a sports car. In the defined phase the company define the requirements of the customer based on inputs from customers historical data industry research the comapny determine what they need to ensure the car becomes a success the data collected indicates customers are drawn to cars which can achieve more than 150 mph. Customers are also more interested in automobiles with V6 engines and an aerodynamic frame, according to the research.
Then in the measure phase the manufacturer uses the customer's requirements to create a specification this specification helps define the product in a measurable method so that data can be collected and compared with specific requirements some of the major specifications that the company focus on are the top speed engine type and type of frame. In the analyze phase the company analyze the product to determine whether there are better ways to achieve the desired

results areas of improvement are determined and testing based on the analysis of the prototype created in this space do the company find that the product satisfies just about all of the customer requirements except the top speed.
After that, research is carried out to determine if an aluminum alloy is capable of meeting the needs of the customer's speed requirements. Following this comes the design phase, where, based on the findings of the analysis phase, the designer develops a new process or product. After the model is revised and the car is manufactured with the new material, the analysis phase is carried out again based on the new design. The management also bring in a focus group and observe how they react to the new material based on their feedback. Further changes are made and finally in the verify phase the company check whether the result meets or exceeds customer requirements once the brand launch the brand-new sports car, they collect customer feedback and incorporate it into future designs and that is DMADV in Six Sigma. A number of different industries the petrochemical, healthcare, banking, governments use Six Sigma to achieve their goals.

5. Lean Six Sigma

An approach to management that seeks to find better methods of doing things has emerged in response to an increasing tendency and worry about competitiveness. In the past, quality control was considered an afterthought to the organization's basic management structure.
As a result, quality has evolved from a subordinate management concept to an overarching phenomena that businesses use to achieve their business goals. There are various quality control and process improvement strategies available in the industrial layouts, but Lean and Six Sigma are well-known and widely used. The Toyota Production System (TPS), sometimes known as the "machine that changed the world," was the inspiration for Lean Six Sigma (Womack et al., 2007) Waste reduction is at the heart of Toyota's Lean philosophy, which is ingrained in the company's culture and DNA. All non-value-added operations that consumers do not want to pay for are referred to as wastes. Ultimately, this results in a process that is structured in a way that solely considers what the consumer wants from the supplier. Six Sigma, on the opposite side of the quadrant and originating at Motorola, places an emphasis on variety. (Antony, 2011). Regardless of how excellent a process is, there will always be some degree of variation in its performance; consequently, the emphasis is on minimizing this variation, both from common and particular sources. When it comes to process improvement, Six Sigma takes a more systematic and data-driven approach, identifying the underlying core causes objectively before making a decision at each stage of the project. A focus on boosting speed or decreasing variance in the process has previously been the typical approach to quality management. By reducing or eliminating waste, the process may move more quickly, but the quality may be degraded as a result of the increased pace and inability to ensure quality. Although quality is unquestionable, minimizing variance takes more time due to the time required to identify the few most important components before formulating a workable solution to the problem. Impromptu solutions are needed to react to the rapidly changing corporate environment. As a result, Lean Six Sigma fusions and hybrids have become more popular in recent years. As competition heats up, more and more firms are focusing on providing top-notch consumer value in a short amount of time. This explains why the merger of Lean and Six Sigma, which has recently received a lot of attention, makes sense. (Yadav & Desai, 2016)

Figure 3: Lean Six Sigma



Source: (*The meaning of Six sigma, Six sigma process, Six sigma explained* https://www.six-sigma-material.com/Six-Sigma-Templates.html)

Lean Six Sigma's hybrid technique is a relatively new idea, particularly since the new century. As a result, academic publications are helping to broaden the field's study. Yet, relatively few thorough and systematic literature reviews on Lean Six Sigma are conducted as part of the study; however, several studies on the isolated technique of Lean or Six Sigma are accessible. With this new development, there is a growing need to comprehend the current research trend in the area of Lean Six Sigma, which provides momentum in understanding the subject's influence on the academic world. The ability to see the results of previous research in this subject would most certainly reveal obvious avenues for future endeavors. (Muraliraj et al., 2018)

Toyota has long been connected with the concept of lean manufacturing. For this reason, Lean was created from TPS (Toyota Production System), which the parent firm employed as a guide for its day-to-day operations and strategic management in dealing with TPS. Waste is a natural part of any operation. Most of the time, people are unaware of the wastes that underlay their activities while they are engaged in them. Waste is referred to in Japan as "Muda." Toyota's "Mura" (unevenness in the process) and "Muri" (overburden in performing duties) are two additional aspects of waste that have not been explained in detail by other authors, despite the fact that several publications have hinted at this. (Hines & Lethbridge, 2008). As a result, Lean's primary goal became the reduction of waste. Everything that may slow down a process is designated as a waste and targeted for eradication, making it easier to streamline operations. Their attention was drawn to what customers wanted (Womack & Jones, 2003), rather than what the company wanted to supply.

6. Advantages & Disadvantages of Six sigma

6.1. Advantages:

With its established track record of adding value to and assuring the quality of a business's output in the form of incremental changes to a product or service, Six Sigma is a proven method of increasing profits and reducing costs. It may also be used to improve the efficiency of supply chain activities and the level of customer satisfaction. As a result, the advantages of Six Sigma go beyond basic problem-solving and take into account the whole manufacturing process from the raw materials to the final product, as opposed to merely the final product.

Six Sigma is a proactive technique that detects and makes remedies for possible issues before the organization suffers any type of financial loss as a result of the problem itself. Six Sigma may be used in a variety of areas within a company, with the results having a direct influence on profitability and cost reduction. Important to note is that the Six Sigma standard for manufacturing goods is a reliable recommendation for B2B clients, indicating that the standard is widely accepted.

6.2. Disadvantages:

In order to achieve Six Sigma, corporate processes must be scrutinized minute by minute, and enormous volumes of empirical data must be collected. This results in time-consuming and sophisticated procedures. Furthermore, since it is really a process of quality improvement, the implementation of its protocols often results in a rise in total expenditures.

When a firm adopts Six Sigma, difficulties might develop when the organization concentrates only on Six Sigma supported rules and loses sight of the company's own mission statement or policies, which can cause problems. For small organizations, it may stifle the development of new ideas that encourage creativity and innovation, but which also need some degree of risk-taking in order to be implemented. Companies must either seek out recognized Six Sigma training schools to teach their personnel or undertake in-house training without obtaining official accreditation. In any situation, the expense of implementing Six Sigma in a small organization is prohibitively expensive and hence unaffordable. Even huge corporations must give extensive training to their personnel in order for them to get familiar with the system.

7. Conclusion

Managing a huge workforce that works across numerous locations, countries, languages, and cultures is tough for any firm, but extremely onerous for manufacturers.
Six Sigma can help analyze time spent on direct and indirect tasks and pinpoint inefficient processes. Let’s assume an organization have too many employees, but poor training or supply chain concerns are slowing output. To solve the problem successfully, a methodical approach across sites helps clarify the issue.
Process flaws cost money. Understanding operations to enhance them is one of the most effective methods to save expenses. The Six Sigma technique is built on a five-step process improvement framework: define, measure, analyze, implement, and control (DMAIC). This technique reduces difficulties to fewer than 3.4 faults per million chances. Reworking damaged items reduces quality costs by 20% and increases operational revenue by 50%. If a company can achieve this improvement across numerous locations, it can actually alter it´s business.
Companies who have been using Six Sigma appropriately for a while have achieved annual profit margin increases of roughly 20% for each Sigma process change (up to 4.8-5.0). Sigma process shifts enable the operator to compute a process's Six Sigma distance. Because most organizations start at 3s, the early Sigma changes have a significant impact on the company's bottom line. Increasing profit margins over time allows enterprises to offer goods and services with more features and functionalities, increasing market share.
Customer-facing activities have a big influence on revenue creation and are a big portion of a company's expense structure. While every client interaction is unique, Sigma realizes that too many variables in front-end operations may be as harmful as too many variables in back-end processes. So that client connections may be strengthened and improved, Six Sigma will find common components that can be standardized. To stay ahead of the competition, data may be leveraged to boost marketing initiatives.
Waste in business and manufacturing may refer to more than just time, money, and resources. Unnecessary information, personnel, and product movement may be identified using Six Sigma. Excess labor procedures that bring no value to the consumer may be a major resource drain. These activities may be minimized, as can overproduction, by indicating where to limit product

and service output beyond immediate usage. So Six Sigma may be a great addition to Lean production.

Employee questions about compensation, contracts, and corporate procedures may slow down work, frustrate employees, and bog down HR and supervisory personnel. Six Sigma can determine what qualifies for overtime, premium time, and vacation pay. Incorrect payments and the time and effort it takes to remedy them may be avoided. Allowing workers to access their own correct payroll data in their own time saves time and boosts morale.

Encouraging a new benchmark for increased performance, Six Sigma is a strong and strategic technique that can help achieve operational excellence. Organizations that adopt this attitude across the board may convert their manufacturing processes into unstoppable global leaders.

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