A Review of Lean Manufacturing, Six Sigma and Lean Six Sigma

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ABSTRACT

Lean manufacturing and Six Sigma are quality techniques used by organizations to meet production targets, enforce standards, reduce waste, and ensure continuous flow of products. While the Lean approach focuses on waste elimination, Six Sigma emphasizes reduction of process variation. This work is an overview of these tools. It gives the history and methodology of Lean and Six Sigma. It also highlights several applications of both methodologies in diverse fields of endeavors.

(Keywords: Lean manufacturing, Six Sigma, Lean Six Sigma, LSS)

INTRODUCTION

In today's manufacturing environment, production is characterized by fluctuating customer demands, complex processes, and inter-disciplinary manufacturing functions. Increased customer demand for products and services have forced many organizations to explore new ways of meeting production targets, enforcing standards, reducing wastes, and ensuring continuous flow of products.

Companies around the world have adopted initiatives that have driven down operating costs and optimized resources whilst increasing profits. These initiatives span business philosophies, marketing drives, quality management tools etc. Gradually, emphasis has shifted to the use of quality tools and techniques because of their multi-variate use in most organizations. Amongst these tools are Lean manufacturing and Six Sigma.

The Lean Approach

Lean manufacturing techniques are founded on methods initiated in the Japanese car manufacturing industry (Odeyinka, Afolabi, and Akinyele, 2018). They have been known to represent techniques that are used for improving that quality of products and efficiency of processes. The basic idea behind this methodology is to eliminate waste. Waste is described as anything that does not infuse value to the end-product from the customers' view. These wastes, transportation, inventory, motion, waiting, overproduction, over processing, and defects, were thought by Ohno (1978) as necessary for removal.

The primary motive of Lean manufacturing is to help manufacturers who desire to improve their operations and become more competitive through the implementation of different Lean tools and techniques. There are five essential steps in Lean:

a) Identify value: Determine the Voice of the Customer (VOC)
b) Identify the sequence of activities called the value stream: The Process Value Stream
c) Make the activities flow: Implement Pull Systems
d) Let the customer pull product or service through the process: Improve Process Flow.
e) Perfect the process: Achieve Lean Perfection or Continuous Improvement

Several Lean tools and techniques have been used to eliminate waste in different manufacturing systems. Figure 1 shows the range of these tools. They include the 5S system, Failure Mode Effect Analysis (FMEA), Kanban, Mistake proofing, Single Minute Exchange of Die (SMED), and Jidoka, among others.

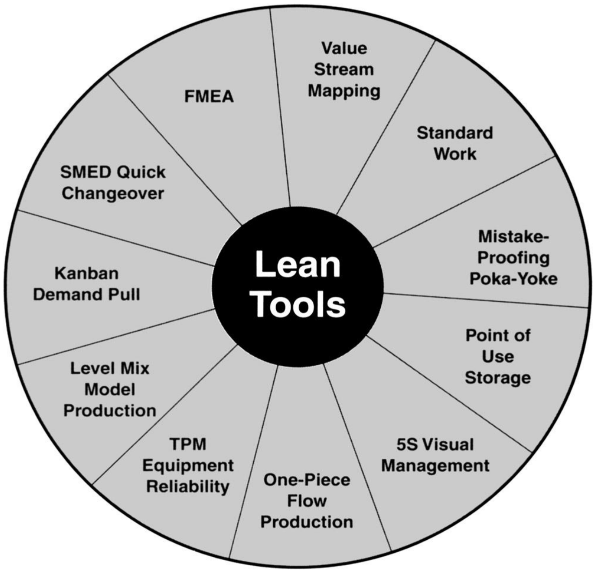

Figure 1: Lean Tools and Techniques.

The tenets of Lean manufacturing, however, predate the 1990s. While recovering from the effects of World War II, Japanese car manufacturers found themselves struggling to catch up with their American counterparts. In order to make improvements, Toyota President, Kichiiro Toyoda ordered "catch up with the Americans in the three years, otherwise, the automobile industry of Japan will not survive" (Ohno, 1978). At that time, it was thought that it took nine Japanese to do what one American could do. Toyota's chief engineer, Taiichi Ohno, who had visited the Ford Motor Company in 1937 observed the over reliance on mass production as a way of cutting costs. This was in order to create the greatest efficiencies as a result of the long set up times. He also noted that this method generated all sorts of waste (muda) and could not work in the Japanese industry that was characterized by low demand and less resources, hence the need for a new system that would suit the Japanese car manufacturing industry.

The Toyota Production System (TPS) thus emerged as a new process-oriented method which reduces costs through optimal resource usage and elimination of wastes. The TPS also had two pillars - Just in Time and Autonomation. Just in Time was used for inventory control so that parts needed will only reach the assembly line when needed in the required quantity. If this was practiced throughout an organization, it would result in "zero inventory". Autonomation means automating a process to include inspection. By the early 1960s, Toyota had come to terms with this method of production.

Though the technique of mass production had become common in most countries, its adoption in Europe had stalled as a result of the outbreak of World War II. It wasn't until the 1950s when companies such as Fiat, Volkswagen, and Renault began to mass produce cars. By this same time, American firms were already losing their competitiveness as top car makers.

By the time of the oil shock of the 1970s, Toyota's profits kept surging and her soaring fortunes continued to be noticed by the world. At the same time, the Japanese car manufacturing industry was making enormous sales to match their American rivals, the need to study the Toyota Production System thus arose.

One of such studies carried out at the Massachusetts Institute of Technology, USA, was the International Motor Vehicle Program (IVMP), which produced the international best-selling book, The Machine That Changed The World, co-authored by Womack, Jones, and Roos. Here, Lean production was coined to define a highly effective production system using minimal resource to yield same number of items with good quality.

Several researchers have attempted to define Lean. Womack and Jones (1996) described Lean as a system where a company can optimize costs, combined with continuous improvements and customer satisfaction. In Sawhney and Ehie (2006), a Lean system is one that decreases the product in-process time while meeting the flexibility requirements associated with the product mix. Maleyeff (2007) considers Lean to be a management approach that aims to maximize value to internal and external customers.

Shah and Ward (2007) defines Lean manufacturing as an integrated socio-technical system that seeks to eliminate waste by concurrently minimizing supplier, customer, and internal variability. In Anvari, Ismail and Hojjati (2011), Lean is regarded to be a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer. Abioye and Bello (2012) described Lean manufacturing as a production philosophy that shortens the time line between the customer's order and shipment through the elimination of waste and adoption of continuous improvement in the production system. (Sanyal, 2015) outlined it as a process which uses optimized space, inventory, lesser defects.

Today, the leadership of Toyota Motor Corporation is undisputed in the car manufacturing industry. Through consistent adaptation and continuous learning, the TPS has been refined over the years and it has become the mainstay of the Japanese manufacturing industry (Abdullah, 2003). Toyota is currently the second largest automobile manufacturer (by production) in the world behind The Volkswagen Group (Wikipedia, 2020) and the 10th-largest company in the world by revenue as of December 2019 (Wikipedia, 2020). The company also reported the production of its 200-millionth vehicle in July 2016. Toyota is also the world's first automobile manufacturer to produce more than 10 million vehicles per year.

REVIEW OF LITERATURES ON LEAN

Various researchers have also attempted to review literatures written in the area of Lean implementation. Dahlgaard-Park and Pettersen (2009) tried to investigate the definition of Lean from 37 articles and 13 books. Zhang, Irfan, Khattak, Zhu and Hassan (2012) did a review study of 116 papers related to Lean Six Sigma. Suárez-Barraza, Tricia Smith and Dahlgaard-Park (2012) analyzed various literatures on Lean Service and classified them into preliminary categories and suggested possible gaps in the research literature from the point of view of researchers and practitioners. Jasti and Kodali (2014) reviewed 178 articles in order to provide a critical assessment of Lean research methodologies.

Nordin, Deros, Wahab, and Rahman (2012) reviewed existing literature for Lean manufacturing approach in the context of organizational change management. They also propose an organizational change framework for Lean manufacturing implementation that can be a basis for further empirical research and validation. Prasanna and Vinodh (2013) explored several research efforts reported in literature on Lean Six Sigma to determine the avenues by which Lean anchorage can be improved in LSS implementation in small and medium-sized enterprises.

Bhamu and Sangwan (2014) reviewed 209 research papers in other to highlight various definitions of Lean, research methodologies used, tools and techniques adopted, and other research contributions in Lean. Sundar, Balaji and Kumar (2014) used exploratory analysis to develop a Lean route map for the organization to implement the Lean manufacturing system.

Kumar, Gazar-Reyes, Rocha-Lona and Upadhyday (2016) explored 70 articles for the environmental (green) impact of using quality and operations improvement methods such as Lean, Six Sigma and Lean Six Sigma. Sreedharan and Raju (2016) reviewed a total of 235 research papers to highlight various definitions by different practitioners for the LSS theme, author profile, country of research, methodology used, industry of study, and year of publication. Nordin, Osman and Ardom (2016) surveyed 68 papers for Lean assessment models.

Tortorella, Fettermann, Frank, and Marodin (2018) surveyed 225 leaders of Brazilian companies implementing Lean in order to understand the relationship between their leadership styles and success of Lean implementation.

Alkhoraif, Rashid, and McLaughlin (2019) reviewed 403 papers to establish the current position of global understanding of Lean implementation in SMEs and the main categories of Lean implementation in the context of SME.

Cudney, Venuthurumilli, Materla, and Jiju (2020) conducted a systematic literature review to identify the relevant opportunities for successful introduction and development of Lean and Six Sigma approaches in higher education.

Basu and Dan (2020) conceptualized a holistic framework for Lean Manufacturing (LM) implementation by reviewing literature survey on the input and output manifests of Lean production.

IMPLEMENTATION OF LEAN

In terms of applications, Lean has been adopted and adapted in a wide range of fields Ezzedine (2006) adapted a Lean assessment model developed by Sanchez and Perez, (2001) to a hospital setting using the 29 Minute Initiative. Erfan (2010) used value stream mapping to expose the waste and implement improvements in the emergency services section of a Libyan hospital. Folinas and Faruna (2011) evaluated the use of Lean thinking as a continuous improvement tool in a Nigerian medical facility.

Sobanski (2002) developed a comprehensive Lean implementation assessment tool for warehousing operations implementing Lean manufacturing principles and techniques. The tool developed provides actionable methods that can be used to advance Lean implementation. Garcia (2015) applied Lean methodologies in improving effectiveness in the public service sector.

Lean in Selected Manufacturing Industries

On a sector basis, Lean finds its application in a wide range of manufacturing fields. Ravikumar, Marimuthu, and Chandramohan (2009) implemented Lean manufacturing methods in an Indian automotive manufacturing plant. Ngoc Le, Ngoc-Hien and Nam (2010) adapted Lean in a South Korean furniture making company. Noorwali (2013) used a Lean model to identify wastes in a food processing system; Khlat, Atef. Harb and Kassem (2014) assessed the extent of implementation of Lean tools in the Lebanese pharmaceutical manufacturing industry.

Abdullah (2003) adapts Lean manufacturing tools and techniques from a discrete to a continuous manufacturing environment (with a focus on the steel industry). The author identified common areas in discrete and continuous manufacturing and tested the ideas in a large steel company. Value stream mapping was used to map the current state and to state the sources of waste. A future state map was then developed for the system with Lean tools applied to it.

Alawode and Ojo (2008) highlighted the implementation of Just In Time (JIT) (which is a related technique) in the Nigerian manufacturing terrain and how its benefits can be harnessed.

Ravikumar, Marimuthu, and Chandramohan (2009) implemented Lean manufacturing methods in an Indian automotive manufacturing plant. The five S (Sort, Set, Shine, Standardize, Sustain) pillar was used to organize the factory shop floor while cellular manufacturing was used to arrange production workstation and equipment in a product-aligned manner that eases flow of components and materials through manufacturing process. Using a 7-Cycle analysis chart, defects such as back passing and by-passing were identified, and a new shop floor layout was developed.

Updhaye et. al. (2009) focused on key issues of inventory, quality, and maintenance in the implementation of Lean manufacturing system. Data was collected from various sources in an Indian manufacturing environment and the results underscored the role of the three issues (quality, inventory, and maintenance).

Abioye and Bello (2012) evaluated the level and implementation of selected Lean manufacturing practices in Nigerian small-scale manufacturing companies.

Lean Implementation In Selected Countries

Lean has been studied in a number of countries. Lean has been studied in the USA more than any other country globally (Bhamu and Sangwan, 2013). Contributions from researchers using real production data have formed the major part of the works on Lean.

Lean has been implemented in a wide range of countries. Sánchez and Pérez (2001) evaluated the influence of certain of Lean indicators in 107 Spanish organizations; Taj (2008) studied Leanness in 65 Chinese firms; Fullerton and Wempe (2008) studied the impact of non-financial manufacturing performance (NFMP) on Lean and financial performance relationship in 121 US companies; Soriano-Meier and Forrester (2002) surveyed over 30 UK Ceramics producing firms to ascertain the degree of Lean implementation; Rahman, Tritos, and Sohal (2010) studied the extent of Lean management practices used in 187 Thailand companies; Tubino, Poler and Da Silva (2011) examined 79 Brazilian organizations for the implementation of Lean practices; Abioye and Bello (2012) analyzed the level of Lean implementation in 58 Nigerian manufacturing companies while Ohiomah and Aigbavboa (2015) studied 33 Nigerian companies to determine the Lean manufacturing tools and adoption barriers encountered.

Similarly, Nwanya and Oko (2019) evaluated the prospects of implementing Lean concepts in Nigeria and concludes that no Nigerian (small or large) enterprise is practicing Lean; Nawanir, Teong, and Othman (2015) mused on the Lean methods of 49 Indonesian firms; Herzog and Tonchia (2014) studied Lean in 72 Slovenian manufacturing companies and Albliwi, Jiju, and Ghadge (2017) surveyed 400 Saudi Arabian organizations for Lean Six Sigma implementation. Overall, Lean has been studied in a wide variety of countries and its awareness level has risen.

SIX SIGMA

Over the years, Six Sigma has been recognized as an efficient strategy for saving costs and improving business processes (Rathi, Khanduja, and Sharma, 2016) as well as optimizing operations, improving quality and eliminating defects (Raghunath and Jayathirtha, 2012).

It is one of the most important and popular developments in the field of process improvement. Six Sigma originated in the eighties (1980s) as a tools kit involving a variety of techniques for manufacturing process improvement (Sujova, Simanova, and Marcinekova, 2016). It was introduced by an engineer, Bill Smith working at Motorola in 1986. Though it evolved from the electronics industry, its use has grown to a variety of sectors (Tjahono, Ball, Vitanov, Scorzafave, Nogueira, Calleja, and Srivastava, 2010).

Six-Sigma is a disciplined, systematic, data-driven approach to process improvement adopted by organizations world over (Sahu and Sridhar, 2013). It is an advanced self-control process that aims to produce or deliver near-perfect products and services (Uluskan, 2016). It uses the Greek symbol "σ" to represent standard deviation away from the mean.

Six Sigma represents six standard deviations away from the mean of the population. The goal of Six Sigma is to create 3.4 or fewer defects per million parts manufactured (opportunities). Two common frameworks for implementing Six sigma are DMAIC (Define, Measure, Analyse, Improve and Control) and DFSS (Design for Six Sigma).

DMAIC Framework

DMAIC is a 5-step process that eliminates non-effective steps, focuses on new metrics, and results in continuous improvement (Kwak and Anbari, 2004). Traditional Six Sigma utilizes DMAIC (Define, Measure, Analyze, Improve and Control). This technique is most effective when applied to an exiting process or to make improvement to a product design.

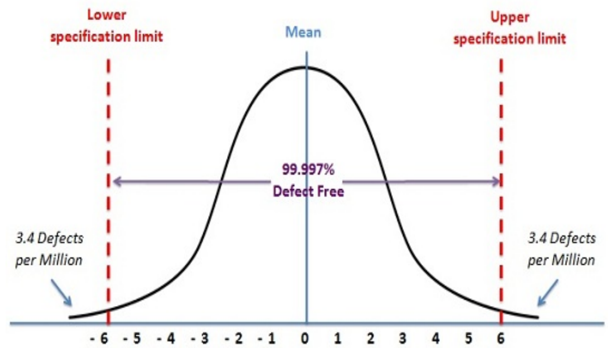

Figure 2: Sigma Quality Level.

I. **DEFINE**: This beginning phase determines the objectives & scope of the project (Tenera and Pinto 2014). The information about the process is collected and the deliverables specified to the customers (both internal and external) Sahu and Sridhar (2013).

II. **MEASURE:** The goal of this stage is to validate (the problem or process), refine (problem or goal), measure (the key steps or input) Ajmera, Umani, and Valase (2017), and establish a baseline of the process capability or sigma level for the process Sahu and Sridhar (2013).

III. **ANALYSE/MODELING:** A model is developed and analyzed based on finding from the measure phase (Kumaravadivel and Natarajan, 2013).

IV. **IMPROVE:** The goal of this stage is to find and implement solutions that eliminates the root causes of problems, and reduce the process variation.

V. **CONTROL**: The process is controlled and monitored for defects. Techniques employed include Kanban, Poka-Yoke, control charts.

Figure 3 depicts the basic DMAIC framework and complements it with the elements of Lean manufacturing.

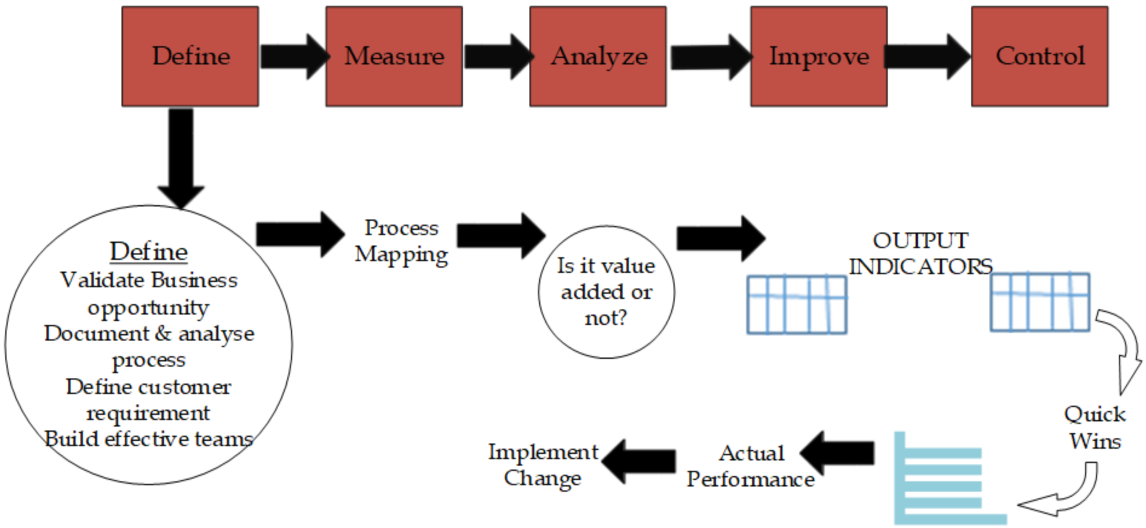

Figure 3: DMAIC Six Sigma Improvement Process.

Design For Six Sigma

Design for Six Sigma (DFSS) is an approach to new product or process development. Its emphasis is on redesigning or replacing products for business organizations (Kumar et. al. 2017). The methods used for DFSS seem to vary according to the business or organization implementing the process. Variants of the DFSS methodology include DMADV (Define, Measure, Analyze, Design, and Verify), DCCDI (Define Customer Concept, Design and Implement), and IDOV (Identify, Design, Optimize and Validate).

The process of activities of DFSS consists of four stages: Identify, Design, Optimize and Validate (IDOV).

a. Identify: Similar to the Define phase of DMAIC, it is driven by the voice of customer or customer need. The key focus in this stage is identifying and establishing customer requirements. These customer needs are to be deployed into Critical to Quality (CTQs) factors that are considered during the product or process design.

b. Design: The target of this stage is to analyze and evaluate the design requirements, key design parameters and their relationship with CTQs.

c. Optimize: The detailed design of products or processes that would meet CTQs are developed and optimized during this phase.

d. Validate: The proposed design is checked to meets the set of customer requirements identified as CTQs.

Comparing DFSS and DMAIC

A comparison of the DFSS and DMAIC methodologies shows that each framework has its own advantage in specific organizational setup.

DFSS DMAIC

A comparison of the DFSS and DMAIC indicates that both are data driven, and well-structured but differ in the type of methodology used, and sigma level achieved.

Table 1: A Comparison of DFSS and DMAIC.

	DFSS	DMAIC
Usage	Used to design or re-design a process from scratch	Used to improve an existing process
Phase	Phases or steps can vary widely, depending on the company, consultant, or training group	Phases or steps are well-defined and widely recognized
Structure	Data-driven, analytical, and highly structured	Data-driven, analytical, and highly structured
Sigma level	Goal Sigma level 4.5 or higher	Goal Sigma level 6.0 or higher
Methodology	Several methodologies to choose from, based on the needs of the business or industry (DMADV, IDOV, DCCDI)	Single methodology with little or no variation

A comparison of the DFSS and DMAIC indicates that both are data driven, and well-structured but differ in the type of methodology used, and sigma level achieved.

SIX SIGMA CERTIFICATIONS

In order to verify the command of the Six Sigma, several companies have adopted certifications that indicate the skill level of individuals. The certifications are denoted by belt colors which specify the skill and mastery level of the holder. They are the White belt, Orange belt, Green belt, Yellow belt, Black belt, and Master black belt.

Green Belt

Green Belts are Six Sigma project leaders that form and facilitate Six Sigma team as well as manage Six Sigma projects from concept to completion. Green Belt training are conducted in line with Six Sigma projects and taken for five days. The training spans quality management, project management, problem solving as well as descriptive data analysis.

Black Belt

Individuals for Black Belt are usually technically inclined. They are actively involved in the organizational change process. Candidates may come from a wide range of disciplines. They are presumed to have mastered a wide range of technical tools. Black Belt candidates have a knowledge in basic mathematics. Black Belts training involve 160 hours of classroom instruction, plus one-on-one project coaching from Master Black Belts or consultants.

Master Belt

This is the highest level of technical and organizational proficiency. Master Black Belts are highly proficient in using Six Sigma methodology to achieve tangible business results. They provide technical leadership of the Six Sigma implementation program. They assist Black and Green Belts in applying the methods correctly. They coordinate and facilitate trainings for Green and Black Belts and also lead the certification board for Six Sigma practitioners.

THE LEAN SIGMA APPROACH

Lean Six Sigma (LSS) is a combination of well-known waste elimination and process improvement techniques - Lean Manufacturing and Six Sigma (Zhang et al., 2012). It is a continuous improvement methodology focused on reducing the costs of poor quality, improving bottom-line results and adding value for customers and shareholders alike (Jiju, 2011), and brings companies many advantages (Pojasek, 2003).

LSS offers a dual approach for process variation reduction and satisfies customers by providing a product that meets their exact needs (Langston, 2015). The Lean approach takes care of waste across all processes and focuses on speed and time. While the Six Sigma strategy focuses on design, eliminating defects, driving out process variability as well as reducing costs (Andersson, Hilletofth, Manfredsson and Hilmola, 2014).

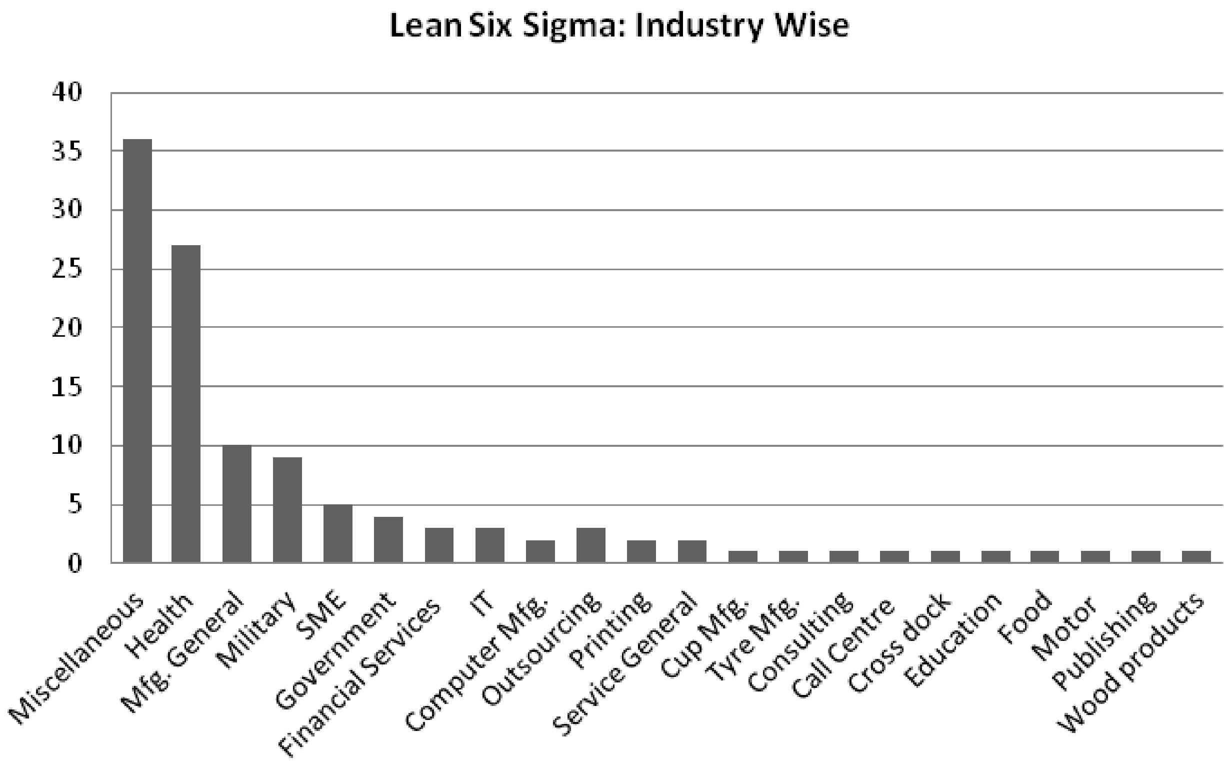

Figure 4: Application of Lean Six Sigma in Different Industries (Source: Zhang et. al, 2012).

Lean Six Sigma Framework

Lean Six Sigma (LSS) tools have a well-established reputation for eliminating waste and improving processes across several sectors, with longevity as proof of their effectiveness. While Six Sigma provides specific statistical tools and engineering techniques for implementing changes, Lean serves as the framework for waste reduction and continuous improvement.

Findings from various studies in LSS show that there are myriads of framework for LSS implementation (Yadav, Seth, and Desai, 2017). Though Yadav, et al (2017) posits that there are inconsistencies in the existing frameworks and associated research trends, Assarlind, Gremyr, and Bäckman (2013) and Raval, and Kant (2017) assert that there is no coherent framework to validate LSS implementation in organizations.

Taylor (2014) even argued that because of the varying interpretations of LSS, no one LSS model that can be compared to either Lean or Six Sigma. More often than not, Lean Six Sigma is based on the commonly used Six Sigma methodologies - DFSS and DMAIC (Kumar et.al, 2016).

In Table 1, a comparison of Six Sigma and Lean manufacturing shows the synergy between them and how they combine under the DMAIC framework to form a structured methodology for improving process and product performance.

Table 2: A Comparison of Lean and Six Sigma under the DMAIC Framework.

Process	Six Sigma	Lean manufacturing
Define	Identify (select) process suitable for improvement.	Identify value from customer stand point -voice of the customer.
Measure	Decide what and how to measure performance of selected process	Identify value stream: Current state mapping
Analyze/Flow	Understand the variables that create process variations.	Analyze the current value stream map.
Improve	Remove causes of defects and modify process.	Improve Process Flow: Invent future value stream.
Control	Maintain improvement	Perfect future map: Sustain improvement.

APPLICATIONS OF LEAN SIX SIGMA

Lean Six Sigma offers a more robust methodology to reducing process variation whilst minimizing waste, its application has been demonstrated by researchers in different manufacturing environments. Its use in manufacturing is prominent but it has been employed in other fields as highlighted by Odeyinka and Sogbesan (2019).

LSS tools also have a well-established reputation for eliminating waste and improving processes across several sectors, with longevity as proof of their effectiveness. Several other implementations of LSS are discussed as follow.

Patel (2011) implemented the Lean Six Sigma DMAIC methodology at Green Belt level in a small Indian packaging company. Major results recorded include a 24% increase in benefits, 72.2% reduction in machine stoppage and 28.3% increase in production.

As a way of implementing LSS in a food safety system to minimize risk, improve productivity and quality of products, and reducing unnecessary waste and time, Zhen (2011) applied LSS tools to minimize physical, chemical and biological hazard contamination probability in frozen salmon processing.

Pusporini, Abhary, and Luong (2013) proposed an environmental performance model based on the DFSS methodology (i.e. identify, design, optimize and validate). DFSS activities and fuzzy logic for the model gives the significant factors of the environmental performance as key indicators for Lean Six Sigma methodology.

J

ie, Kamaruddin and Azid (2014) developed a LSS framework for a SME label printing company. The company produces various types of labels such as computer labels, offset & silkscreen stickers and bar code labels. Using LSS, the company production capacity was shown to have an extra 896,000 impression/hour capacity in order to help the company cope with customer demands. This extra of capacity is worth two months of the current capacity in the label printing production and an overall 21.93% improvement.

Andersson et. al. (2014) developed a strategy for adopting LSS in a telecommunication manufacturing firm (Ericsson). By collecting empirical data mainly from on-site interviews and observation, an improvement project was developed to address difficulties related to delivery precision and long lead times of the company's MINI-LINK production line. The use of the LSS strategy improved flexibility, robustness, cost-efficiency, and agility of the production line at the same time.

Panat, Dimitrova, Selvamuniandy, Ishiko, and Sun (2014) adopted the LSS methodology to systematically eliminate waste and improve the existing process of Intel's configuration control during the development and ramp phases. Results indicates an efficiency improvement of 60% reduction in idle time and waste (above the 40% target). Improved stakeholders' satisfaction was also recorded.

Langston (2015) investigated the use of Lean Six Sigma in reducing the error rate in tower foundation construction. The work developed a foundation installation manual using the DMAIC methodology and waste reduction tools. The results showed a significant reduction in the error rate of foundation installation after distribution and implementation of the manual.

Cirrone, Di Pietro, La Corte and Torrisi (2016) developed a structured approach using super network framework and LSS to model and optimize patient flows in hospital systems. A case study of patient flow in an emergency department is considered. The method proved to be valuable in analyzing the problem and improved the decision-making process, while providing tools to study the problem, applying efficient algorithms for computation, and providing visual aids to see the dynamic changes.

Venanzi, Faustino, da Silva and Hasegawa (2017) used LSS to increase profitability in production system and to reduce the consumption of tools and machine optimization in the production line of an auto parts supplier company.

Aldairi, Khan, and Munive-Hernandez (2017) developed a knowledge-based Lean Six Sigma maintenance system for sustainable buildings. The LSS based maintenance framework was developed using the rule-based approach of knowledge systems and the gauge absence prerequisites (GAP) technique. The developed framework assesses organizational capabilities through five strategic and operational levels thereby improving sustainable building performance.

Ajmera et. al. (2017) adopted a structured approach in implementing LSS in a textile manufacturing firm. The textile factory's operating capacity was at a defect percentage of 8.25. On LSS implementation, the percentage defect was reduced to 2.63. There was also significant improvement in the Sigma level of the factory from 2.9 to 3.1.

Feng, Zhang, Wang, and Li (2018) used the LSS DMAIC framework to reduce in-process defective and improve first time success in a lamp assembly process. Several LSS tools were employed to the lower operation costs, lift quality level and enhance competitiveness in the organization.

Hill, Thomas, Mason-Jones, and El-Kateb (2018) outlined a novel implementation of the LSS framework in an aerospace Maintenance Repair and Overhaul (MRO) facility. Factors that affect supply chain performance were identified and the effectiveness of the framework was measured through performance metrics.

Gijo, Palod, and Jiju (2018) illustrated the use of LSS methodology in an Indian Auto-ancillary conglomerate. The application of the methodology resulted in reduction of drilling defects and a significant financial impact on the company bottom-line.

Orynycz, Tucki and Prystasz (2020) used LSS tools to decrease the energy consumption and CO_2 emissions in a fast-food restaurant.

SUMMARY

Overall, the usefulness of Lean, Six Sigma and Lean Six Sigma cannot be over-emphasized. They provide structured approaches to optimizing processes thereby reducing cost, increasing profits and achieving company objectives. Asides the long-term cost savings, these techniques use a wide array of tools that help organizations improve business processes and increase product performance.

This review highlights the history and methodology of Lean and Six Sigma. It also highlights several applications of both methodologies in diverse fields of endeavors. It shows an apparent preoccupation with tools and techniques as shown in individual case studies. These case studies do show individual savings and benefits such as reduction of wastes and variation, increase in profits, optimization of resources and many more.

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