Chapter

Lean Six Sigma in Manufacturing: A Comprehensive Review

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Abstract

Lean Six Sigma is a systematic approach to reduce or eliminate activities that do not add value to the process. It highlights removing wasteful steps in a process and taking the only value added steps. The lean six sigma method ensures high quality and customer satisfaction in the manufacturing. The main purpose of this chapter is to explore the Lean Six Sigma (LSS) in the manufacturing sector. This chapter focuses on the different critical aspects of LSS. The core sections of this chapter are Introduction; Key lean six sigma principles; Tools and techniques; Lean six sigma methodologies; Critical success factors; Lean six sigma framework; Lean six sigma strategy; Implementation of Lean Six Sigma in SMEs; significant benefits; Significant barriers to implement lean; Assessment of Lean Six Sigma Readiness; Emerging trends in Lean Six Sigma; and Successful examples/stories in the manufacturing industry. The final section of the chapter contains the conclusions and suggestions. It is important for practitioners to be aware of Lean six sigma benefits, impeding factors, Tools and techniques, methodologies etc. before starting the Lean six sigma implementation process. Hence, this chapter could provide valuable insights to practitioners. It also gives an opportunity to Lean six sigma researchers to understand some common themes within this chapter in depth.

Keywords: lean, six sigma, lean six sigma (LSS), manufacturing, comprehensive review, methodologies, success factors, principles, lean six sigma examples

1. Introduction

In recent years, Lean Six Sigma have become the most popular business strategies for deploying continuous improvement [1] in manufacturing sectors, as well as in the public sector. Continuous improvement is the main aim for any organization in the world to help them to achieve quality and operational excellence and to enhance performance [2, 3].

It has changed manufacturing forever and from every aspect of the industry: from the people and the machinery to the logistics and administration. According to SAIL engineer Srivastva, "Machines mean nothing; if they are not efficient and calibrated—this is where the Six Sigma Methodology and the Machine Industry marry their goals for the betterment of the business industry".

There is a misconception that Lean and Lean Six Sigma methodologies are only applicable to manufacturing or supply chain processes [4, 5]. However, these tools can be used within all aspects of a business [6]. The essential foundation needed for Lean and Lean Six Sigma methods succeed within all areas of a company is the capability to recognize waste, decrease the waste, and forcefully attempt to eliminate all activities that do not add value or increase customer satisfaction both within the company and outside.

These methods are not a new phenomenon. In fact, the Lean methodology has been an effective tool since the dawn of the industrial age [7, 8]. The idea of improving performance and meeting the expectations of customers while still improving the bottom line has always been the goal of businesses [9]. The evolution of Lean and Lean Six Sigma is based on understanding what methods or mixture of methods should be used to ensure the biggest impact to the business. The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) foundation is the base for our Lean training and service programs [10, 11].

Six Sigma basics are designed to improve manufacturing [12, 13]. This is a type of quality control that was originally developed for large scale manufacturers. It was intended to enhance processes and eliminate the amount of defects found within them. The Lean method is a philosophy centered around eliminating waste and providing the best customer experience [14]. According to the Lean manufacturing subject matter expert, there are eight kinds of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing.

Researchers believe that it is very important to conduct a comprehensive review in manufacturing field to understand the each aspect of Lean Six Sigma. Research on "Lean Six Sigma in manufacturing" is limited and state that no standard work done for such a combination exists.

Hence, the aim of this chapter is to address such gaps within Lean Six Sigma (LSS) and manufacturing that allow them to achieve the most benefits from this strategy, as well as to identify the gaps and give recommendations for future research. To achieve the overall aims of this chapter, the author has comprehensively reviewed the literatures in second section.

2. Comprehensive review

2.1 Lean and six sigma

The concept of lean thinking can be traced to the Toyota production system (TPS), a manufacturing philosophy pioneered by the Japanese engineers Taiichi Ohno and Shigeo Shingo [15, 16]. The development of this approach to manufacturing began shortly after the Second World War while employed by the Toyota motor company [17]. Lean manufacturing extends the scope of the Toyota production philosophy [18] by providing an enterprise-wide term that draws together the five elements of "the product development process, the supplier management process, the customer management process, and the policy focusing process for the whole enterprise" [17]. Lean Six Sigma has been defined as "a business improvement methodology that aims to maximize shareholders' value by improving quality, speed, customer satisfaction, and costs: it achieves this by merging tools and principles from both Lean and Six Sigma" [19]. Gershon and Rajashekharaiah [20] point out that "leading texts fail to define Lean Six Sigma as a unique methodology".

Laureani and Antony [21] stated that "Lean Six Sigma uses tools from both toolboxes in order to get the best from the two methodologies, increasing speed while also increasing accuracy". Both Lean and Six Sigma require a company to focus on its products and customers [19]. According to Stoiljković et al. [22], the concepts of lean and six sigma are intertwined in that Lean speed enables Six Sigma quality and Six Sigma quality enables Lean speed. Pepper and Spedding [17] and Ferng and Price [23] similarly identify that Lean thinking may be used to identify areas of improvement

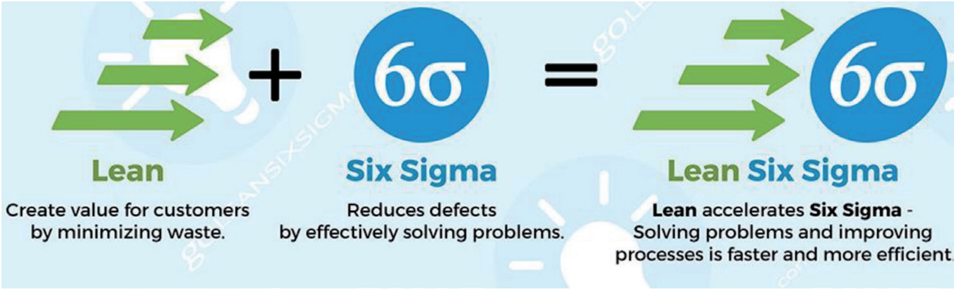

Figure 1.
Lean, six sigma and lean six sigma. Source: [27].

and set standards, while the Six Sigma methodology may be used for targeting them and for investigating deviations from said standards. The foundation of the lean vision is still a focus on the individual product and its value stream (identifying value-added and non-value added activities), and the main target of lean thinking is to eliminate all waste, or muda, in all areas and functions within the system [16, 17].

Lean Six Sigma is a combination of two powerful process improvement methods: Lean and Six Sigma [24–26]. It decreases organization's costs by:

- Removing "Waste" from a process: Waste is any activity within a process that is not required to manufacture a product or provide a service that is up to specification [36, 37].

- Solving problems caused by a process: Problems are defects in a product or service that cost your organization money [36, 37] (**Figure 1**).

2.2 Integrating lean and six sigma

Lean and Six Sigma are the two most important continuous improvement (CI) methodologies for achieving operational and service excellence in any organization [29–33]. LSS is the fusion of two most powerful process excellence methodologies, namely, Lean and Six Sigma [24].

According to Sokovic and Pavletic [34] *Lean* means speed and quick action (reducing unnecessary wait time) and *Six Sigma* means identifying defects and eliminating them. As well as *Lean Six Sigma Engineering* means best-in-class. It creates value in the manufacturing or service organization to benefit its customers and saves money without capital investment [34].

Six Sigma is a well-established approach that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those process performance characteristics that are of critical importance to customers' [35]. It is a statistical methodology that aims to reduce variation in any process, reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction, measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization [35, 36].

The high cost of Six Sigma training is a barrier for many organizations to deploy this methodology [37, 38]. In fact, deploying Six Sigma in isolation cannot remove all types of waste from the process, and deploying Lean management in isolation cannot control the process statistically and remove variation from the process [35]. Therefore, some companies have decided to merge both methodologies to overcome the weaknesses of these two methodologies when they have been implemented in isolation and to come up with more powerful strategy for continuous improvement

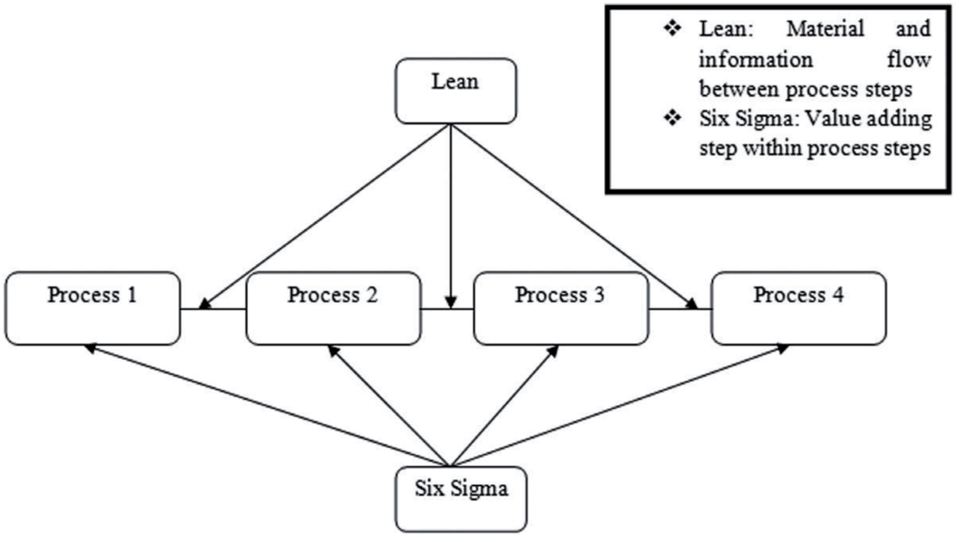

Figure 2.
Concept of lean six sigma. Source: [28].

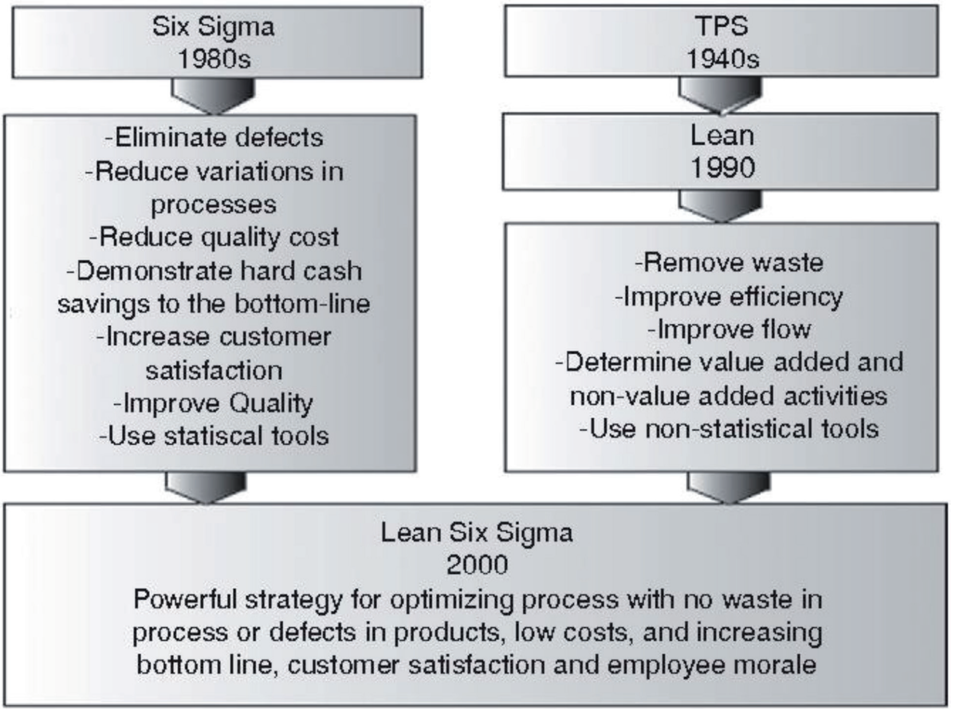

Figure 3.
Lean and six sigma popularity and integration. Source: [35].

and optimizing processes [35, 39, 40]. In fact, LSS are completing each other and there is an obvious relation between both methodologies, which makes it possible for the synergy of the two methodologies (see **Figures 2** and **3**). Therefore, the integration of these two approaches gives the organization more efficiency and affectivity and helps to achieve superior performance faster than the implementation of each approach in isolation [30, 35, 41].

Salah et al. [30] has indicated that the integration of lean and Six Sigma is the solution to overcome the shortcomings of both, as they complete each other. This integration helps companies to achieve zero defects and fast delivery at low cost. According to Bhuiyan and Baghel [42] the combination of this two is the way for organizations to increase their potential improvement.

The integrated approach to process improvement (using Lean and Six Sigma) will include:

- Using value stream mapping to develop a pipeline of projects that lend themselves either to applying Six Sigma or Lean tools [34, 43].

- Teaching Lean principles first to increase momentum, introducing the Six Sigma process later on to tackle the more advanced problems [34, 43].

- Adjusting the content of the training to the needs of the specific organization—while some manufacturing locations could benefit from implementing the Lean principles with respect to housekeeping, others will have these basics already in place and will be ready for advanced tools [34, 43].

The following roadmap provides an example for how one could approach the integration of Lean and Six Sigma into a comprehensive roadmap (**Figure 4**).

Therefore, many manufacturing firms are looking for an approach that allows to combines both methodologies into an integrated system or improvement roadmap [44, 45]. However, the differences between the Six Sigma and Lean are profound (**Table 1**).

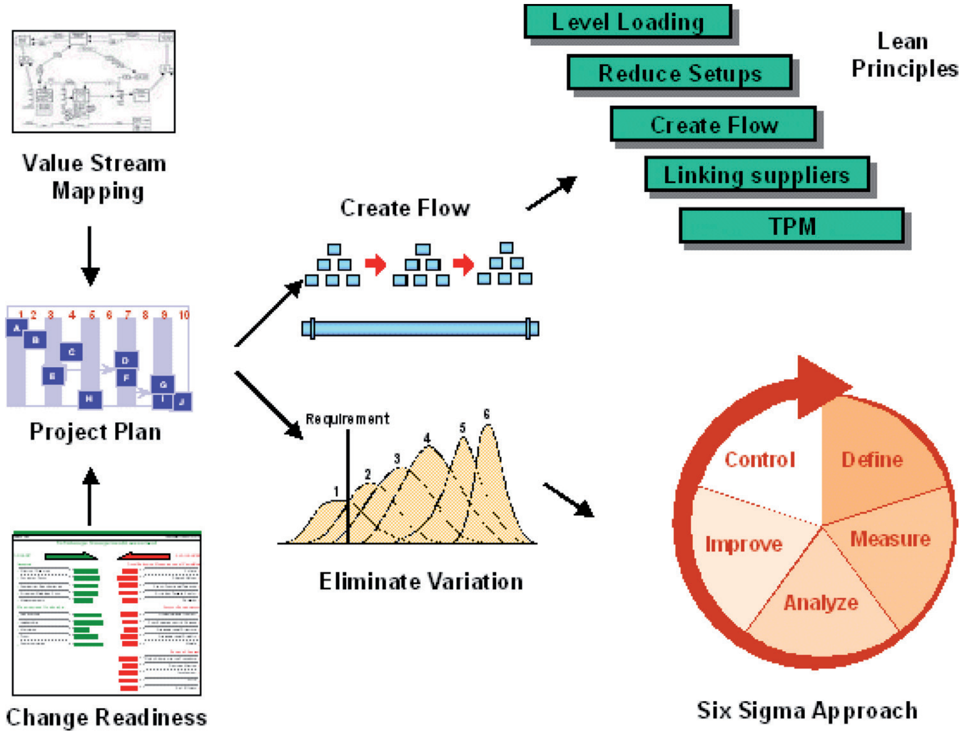

Figure 4.
Integrating lean and six sigma roadmap. Source: [44].

	Lean	Six sigma
Goal	Create flow and eliminate waste	Improve process capability and eliminate variation
Application	Primarily manufacturing processes	All business processes
Approach	Teaching principles and "cookbook style" implementation based on best practice	Teaching a generic problem-solving approach relying on statistics
Project selection	Driven by value stream map	Various approaches
Length of projects	1 week to 3 months	2–6 months
Infrastructure	Mostly ad-hoc, no or little formal training	Dedicated resources, broad-based training
Training	Learning by doing	Learning by doing

Source: Prepared by the author.

Table 1.
Comparing lean and six sigma.

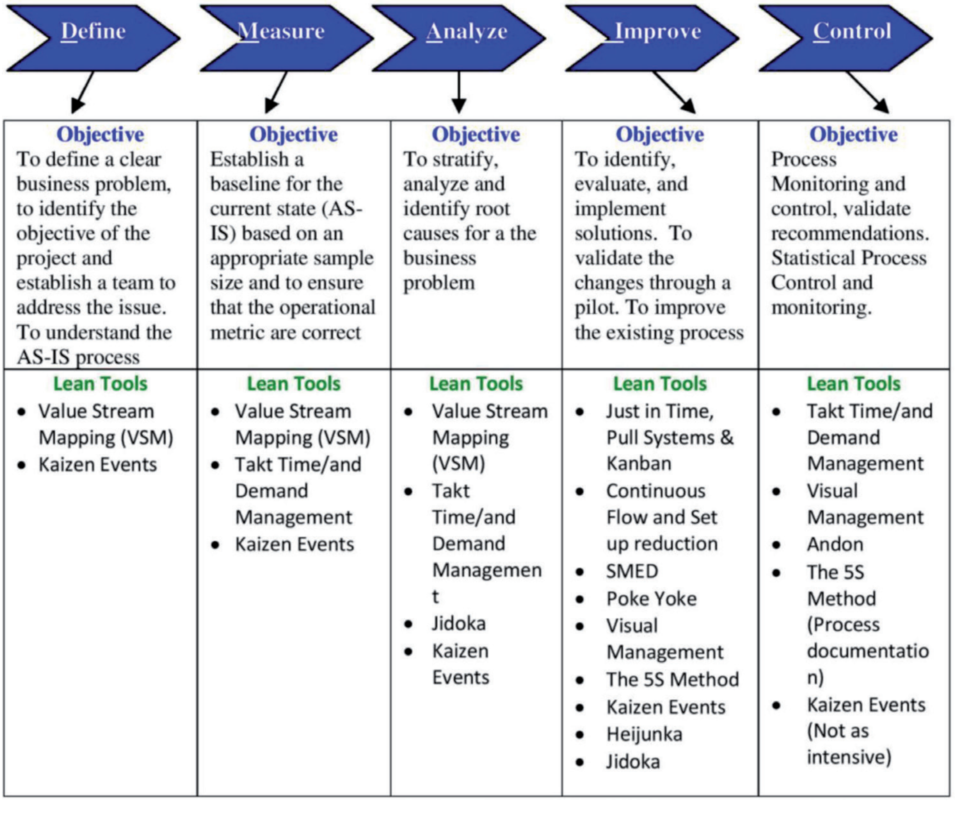

Figure 5.
Integrating lean tools and six sigma DMAIC cycle. Source: [46].

Duarte [46] identify that Lean Six Sigma has become a widely recognized process improvement methodology and has been adopted by many companies like Ford, DuPont, 3 M, Dow Chemicals, and Honeywell etc. At present, the methodology of Lean Six Sigma has been carried out in 35% of companies listed in the Forbes top 500 [46]. He illustrates how Lean tools can be incorporated into the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) cycle (**Figure 5**).

2.3 Basics of lean six sigma

In the efforts to draw nearer to customers, several manufacturers have lost focus on what ought to be a company's primary success factor—profitable growth. In today's competitive manufacturing environment, it takes more than quick fixes, outsourcing and downsizing for firms to systematically achieve their growth and profit objectives [47]. Whereas these choices could yield temporary financial relief, they will not lead the way to long-term growth and profitability. Therefore, they have to bring lean to grow and continually exceed bottom line expectations; and to bring lean they must master eight basics of Lean Six Sigma for manufacturing.

2.3.1 Software as the solution

In digital and cloud based environment, the physical database is replaced by a virtual database. Data are transferred throughout the cloud computing [48]. Organizations were led to believe that computerized systems would provide the solution to all growth and profit challenges. Material requirements planning (MRP) and enterprise resource planning (ERP) system gurus assured companies that if they implement their software programs at bottom line, would take care of itself. In a typical company, converting the quarterly financial forecast into reality still requires overtime, internal/external expediting, last minute "on-the-run" product changes and even some "smoke and mirrors" from time to time [49]. Results are scrap, rework and warranty costs that negatively impact profitability and quality, and shipment problems that deliver less than acceptable customer satisfaction [47]. Companies have spent thousands of dollars in pursuing MRP and ERP only to see growth and profits decline due to uncontrolled operating costs that produced non-competitive pricing [39, 40]. Thus, softwares can be a solution for these problems, and eliminate the root causes of ineffective systems and processes.

2.3.2 How to get to root causes

Manufacturers can get the root causes by in-depth understanding of the fundamentals of Six Sigma and then a total reliable commitment and determined execution of eight basics of Lean Six Sigma. Like renowned football coach Vince Lombardi, who achieved success by having his team focus on the mastery of football basics, manufacturing teams need to focus on the mastery of the Lean manufacturing basics. These basics require proactive planning and inflexible implementation that demands leadership above and beyond just satisfying day-to-day accountabilities. Some managers cannot imagine the benefits of mastering manufacturing basics. Others simply cannot find the time. Like practicing blocking and tackling in football, it is not exciting. And like most football heroes, managers prefer to run with the ball. But without the solid execution of Lean Six Sigma basics, companies will seldom achieve their full growth and profit potentials [44, 47]. Here are the eight basics of Lean Six Sigma which every manager should know and implement:

- **Information integrity:** It is common for front office management to become disappointed with computerized systems results when time schedules and promised paybacks are not achieved. It is a given that acceptable systems results cannot be achieved when systems are driven by incorrect data and inappropriate, uncontrolled documentation [44, 47, 50].

- **Performance management:** Measurement systems can be motivational or de-motivational. The individual goal-setting of the 1980s is a good example of de-motivational measurement—it tested one individual or group against the other and while satisfying some individual egos, it provided little contribution to overall company growth and profit. Today, the balanced scorecard is the choice of business winners [44, 47, 50].

- **Sequential production:** It takes more than systems sophistication for manufacturing companies to gain control of factory operations. To achieve on-time shipments at healthy profit margins, companies need to replace obsolete shop scheduling methodology with the simplicity of sequential production [51]. Manufacturing leaders have replaced their shop order "launch and expedite" methodology with continuous production lines that are supported by real-time, visual material supply chains...sequential production. The assertion that sequential production only works in high production, widget-manufacturing environments is a myth [44, 47, 50].

- **Point-of-use logistics:** Material handling and storage are two of manufacturing's high cost, non-value-added activities. The elimination of the stock room, as it is known today, should be a strategic objective of all manufacturers. Moving production parts and components from the stockroom to their production point of use is truly a return to basics and a significant cost reducer [44, 47].

- **Cycle time management:** Long cycle times are symptoms of poor manufacturing performance and high non-value-added costs [44, 52]. Manufacturers need to focus on the continuous reduction of all cycle times. Achieving success requires a specific management style that focuses on root cause, proactive problem solving, rather than "fire-fighting" [44, 47].

- **Production linearity:** Companies will never achieve their full profit potential if they produce more than 25% of their monthly shipment plan in the last week of the month or more than 33% of their quarterly shipment plan in the last month of the quarter. How linear does a production department produce to the company's master schedule? As companies struggle to remain competitive, one of the strategies by which gains in speed, quality and costs can be achieved is to form teams of employees to pursue and achieve linear production [44, 47].

- **Resource planning:** One of the major challenges in industry today is the timely right sizing of operations. Profit margins can be eroded by not taking timely downsizing actions, and market windows can be missed and customers lost by not upsizing the direct labor force in a timely manner. These actions demand timely, tough decisions that require accurate, well-timed and reliable resource information [44, 47].

- **Customer satisfaction:** Customer satisfaction is the main driver of loyalty. It affects company's financial performance and perception of the customers [53]. Perceptions are what a company needs to address when it comes to improving customer satisfaction. It does not good to have the best products and services if the customer's perception of "as received" quality and service is unsatisfactory. Companies need to plan and implement proactive projects that breakdown the communication barriers that create invalid customer perceptions [44, 47, 54, 55].

2.4 Key lean six sigma principles

Lean six sigma principles mainly refer to process improvements, although their practical implementation has different impacts according to different organizational models [56]. Leaders at all levels are working to integrate lean and Six Sigma principles into all business processes, including product design and development, integrated supply chain, marketing and sales, customer service, infrastructure, governance and strategy deployment [57].

According to Lucid chart Content Team, for a process stream that produces the best results; consider the following Lean Six Sigma principles for your organization.

1. **Focus on the customer**: Before you start making any drastic or even minor changes, establish the level of quality or requirements that you have promised your customers.

2. **Figure out your value stream**: You need to see the current state of your process before you can move forward and make improvements. Identifying value stream is unquestionably what makes Lean Six Sigma principles so effective. A value stream map showcases every single step, including purchasing parts, assembling them (and checking for quality assurance), and distributing the finished product. You must determine which steps add value and which do not.

3. **Take out the trash**: Remove any non-value-added activities or opportunities for defects. On value stream map, avoid highlighting areas that are working fluidly. If your value stream map does not clarify exactly where the problem lies, you can use several other diagrams to work through potential root causes of the issue. For example: Cause-and-effect diagrams.

4. **Keep the ball rolling**: Workers will keep performing (or not performing) the same tasks until management decides otherwise. The responsibility of business is to communicate the new standards and practices effectively and clearly. Be sure each employee receives training and feedback. Otherwise, why expect the problem to change? Thus, nothing will change until change is enacted.

5. **Create a culture of change and flexibility**: Lean Six Sigma requires a lot of change [58]. You need to welcome change and encourage your employees to accept change as well. As part of this cultural shift, your company should always look for new ways to streamline the process and remove waste. Keep your eye on the data, examine your bottom line, and adjust your processes where necessary.

Womack and Jones [59] has summarized five Lean Six Sigma Principles in "Lean thinking—banish waste and create wealth in your corporation" as follows:

1. **Specifying value:** "Value is only meaningful when expressed in terms of a specific product or service which meets the customer needs at a specific price at a specific time."

2. **Identify and create value streams:** "A Value stream is all the actions currently required to bring a product from raw materials into the arms of the customer."

3. **Making value flow:** "Products should flow through a lean organization at the rate that the customer needs them, without being caught up in inventory or delayed."

4. **Pull production not push:** "Only make as required. Pull the value according to the customer's demand."

5. **Striving for perfection:** "Perfection does not just mean quality. It means producing exactly what the customer wants, exactly when the customer requires it, at a fair price and with minimum waste."

Womack et al. [60] defined the five principles of Lean manufacturing in their book "The Machine That Changed the World". The five principles are considered a recipe for improving workplace efficiency and include: (1) defining value, (2) mapping the value stream, (3) creating flow, (4) using a pull system, and (5) pursuing perfection. The principles encourage creating better flow in work processes and developing a continuous improvement culture. By practicing all these five principles, an organization can remain competitive, increase the value delivered to the customers, decrease the cost of doing business, and increase their profitability. These Lean principles can be applied to any process to reduce the wastes (**Figure 6**).

2.5 Lean six sigma frameworks and methodologies

Lean six sigma is a systematic data driven methodological philosophy centered around eliminating waste, reducing process variation [61] and providing the best customer experience [45]. According to the Lean method, there are eight kinds of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing [62]. Lean six sigma is a structured problem solving methodology [63]. The lean six sigma framework aim at providing an effective approach to integrating lean and six sigma [65]. It uses the DMAIC phases similar to that of Six Sigma [32]. Problem solving in lean Six Sigma is done using the DMAIC framework. It has been implemented and verified at one engineering company in UAE [32]. The results show that the process "Make-to-Order (MTO) projects" has a long lead-time [32]. The main causes of the long lead-time are the subcontractors, the customers, and the company-implemented procedures [32].

Figure 6.
The five lean principles [64].

Using the framework, it was possible to identify the most significant reason for the long lead-time, analyze the root-cause(s), suggest three relevant solutions and select the most preferred one [32]. In this methodology framework application, lean-production, six-sigma, balanced scorecard, simulation and cost benefit analysis tools were used.

A study was conducted in India by Ben Ruben et al. [61] using DMAIC framework methodology and validated practically to provide both operational and environmental benefits. The framework is validated with an industrial case study conducted in an Indian automotive component manufacturing firm/organization located at Tamilnadu. The firm manufactures high precision transmission. On the successful deployment of the framework, the internal defects was brought down to 6000 ppm from 16,000 ppm and environmental impacts was reduced to 33 Pt from 42 Pt. Deployment of the developed framework helped in improving the firm's sigma level and also reduced the overall environmental impacts. In this research different lean six sigma tools were used at different level/phase like-Value Stream Mapping (VSM), 5S, Kaizen, Cause and effect diagram, Quality Function Deployment (QFD), High level SIPOC, Eco-QFD, Pareto chart, Environmental VSM (current level), life Cycle Impact Assessment, Brainstorming, Design of Experiments, Cost benefit analysis, Design for Environment, Life Cycle Interpretation, Environmental VSM (Future level), 7s practices, Standard operating Procedure (with environmental metrics) and Performance evaluation tools.

Thus, using the framework methodology the user will have a systematic approach for continues improvement. Because, this framework also allows the user identify the process problem(s) and solve them effectively [32]. There are five stages in this framework. They are Define, Measure, Analyze, Improve, and Control [66] (**Figure 7**).

Hill et al. [45] has developed an initial conceptual Lean Six Sigma Framework (LSSF) and undertook a series of iterative developments in an attempt to improve its effectiveness and suitability to Maintenance Repair and Overhaul (MRO) implementation. Hill et al. [45] describes the novel implementation of an integrated LSS framework and outlines how it was used to identify the factors that affect supply chain performance in an aerospace Maintenance Repair and Overhaul (MRO) facility. It shows how each of the Six Sigma DMAIC phases are applied systematically to each of the Lean stages. Stage (0) of the LSSF was the starting point of the implementation stage. *The phases are as follows:*

LSS Phase 1—Specify value by defining the CTQ issue.

LSS Phase 2—Align the internal operations through measuring the extent of the Problem.

LSS Phase 3—Create flow by identifying constraints in the system.

LSS Phase 4—Create flow through process improvement.

LSS Phase 5—Continuous improvement and control of future processes (**Figure 8**).

Hill et al. [45] outlined the application and measures the effectiveness of the integrated LSS framework through its ability to achieve new and enhanced performance through simultaneously reducing late material calls and reducing and stabilizing Order To Receipt (OTR) times.

2.6 Tools and techniques

Lean and Six Sigma both have their own set of tools and techniques that can enhance a company's objectives for value and profit enhancement [24]. Lean six sigma consists of many tools and techniques for continuous improvement such as the Kanban system, 5S, Cause and Effect analysis (C&E), Value Stream Mapping (VSM) and many others [35, 36]. According to Brazilian publications, there are

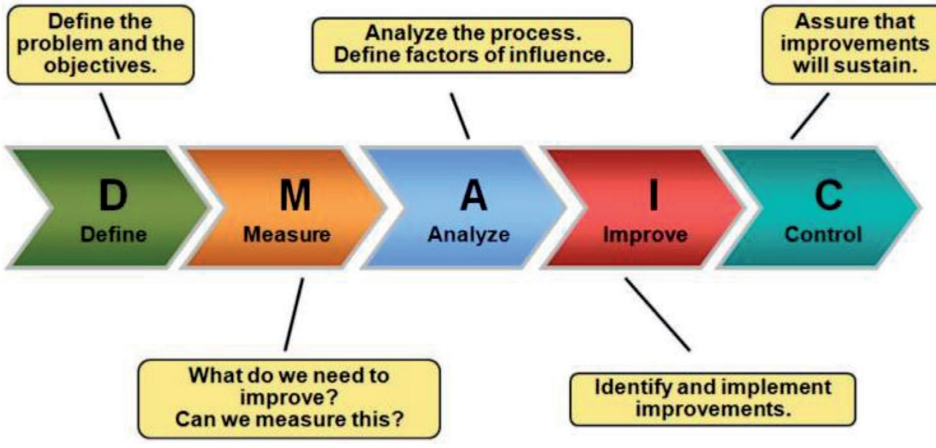

Figure 7.
Lean six sigma framework and methodology. Source: [66].

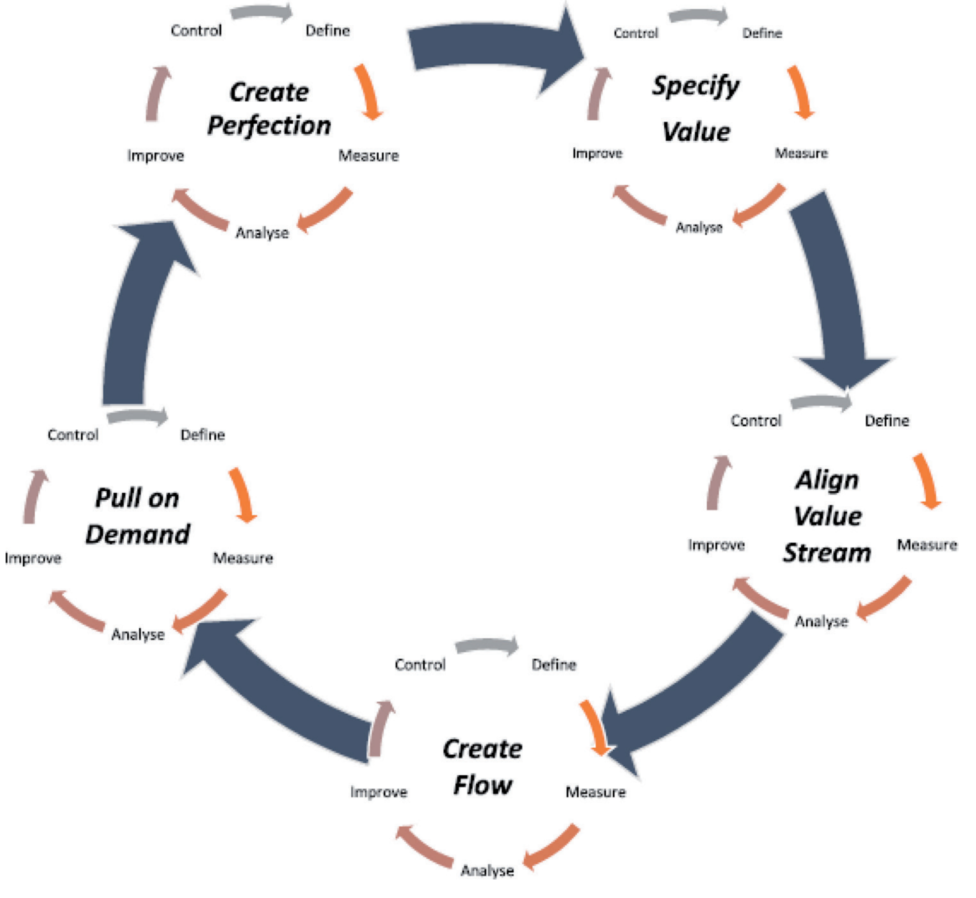

Figure 8.
Integrated generic lean six sigma framework (LSSF). Source: [45].

six most frequently tools used in LSS applications: "Control Charts", followed by "Value Stream Mapping", "DMAIC," "Kaizen," "Ishikawa Diagram," and "Histogram;" and Control chart is the top ranking tool [33]. DMAIC is a five step

Lean Six Sigma (LSS) tools	Author(s)
Control Charts	[10, 24, 33, 67]
Value Stream Mapping (VSM), Box plot, Process mapping, Standardized work, Scatter diagram, Cause and effect matrix (C&E analysis), Kanban system, Hypothesis Testing, Process Flow Diagram, Quick, 7 waste analysis, Heijunka	[10, 24, 31, 35, 67]
DMAIC or DMADV	[10, 24, 67, 68]
Kaizen, Single Minute Exchange of Die (SMED)	[24, 67, 68]
Ishikawa Diagram, Histogram, Stratification	[10, 24]
Pareto Chart, E-Kanban system, SOP, Check sheet, VOC translation matrix, Three diagrams, Brainstorming, SIPOC Diagram	[10, 24, 31]
Current state map, Spaghetti diagram, Poka-yoke	[24, 67]
5S, 5 Whys, XY matrix, FMEA, ANOVA, Design of Experiments (DOE), Rootcause Analysis, Mistake proofing, VSM, Pareto chart, CTQ analysis, Root-cause analysis, Jidoka	[10, 24, 31, 35, 67]
Process Capacity Analysis, Cause and effect diagram	[10, 24, 31]
Changeover, Total Productive Maintenance (TPM), Line balancing; Cellular manufacturing,	[24, 67]
Critical to Customer Tree—VOC/VOB	[24]
OEE, DMADV, Autonomation (Jidoka), Visual management	[24]
5W1H, JIT, Regression analysis, QFD, Statistical Process Control (SPC), Kano Model, Gemba (Go & See)	[24, 31, 35, 39, 67, 68]
Confidence Interval, Continuous Flow, Benchmarking	[24]
Impact Effort Matrix, PDCA, DFSS, Production Leveling, Lean Office, Solution Prioritization Matrix, Matrix Diagram,	[24]
QCC (Quality Control Circle), Cellular Layout, Milkrun, Mizusumashi	[24]
Andon, QC Story, Routine Management, R&R, Gantt Chart	[67]
Relationship Diagram, Stratification, Cross-functional Team, Theory of Constraints (TOC) Principles, A3 Form, Affinity Diagram	[67, 69]

Source: Prepared by the author.

Table 2.
Identified lean six sigma tools and techniques.

method for improving existing process problems with unknown causes. DMAIC define and quantify the problems; identify cause of the problems; implement, verify and maintain the solutions. The DMAIC or DMADV toolkit comprises all the Six Sigma and Lean tools [10], and the success factors of lean six sigma is their ability to use the toolbox in a systematic and disciplined manner [10]. Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Statistical Process Control (SPC), Design of Experiments (DOE), Analysis of Variance (ANOVA), Kano Model, etc. statistical tools and techniques reduce variation in any process, reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction, measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization [35, 39]. Some of these tools have adopted from TQM as Six Sigma in itself has derived from the TQM movement. All the tools and techniques are shown in **Table 2**.

2.7 Critical success factors

There are many studies have been conducted on critical success factors of LSS. Author has shown critical success factors that were identified by previous researchers. Some of the predominant CSFs are discussed in this section.

Most studies on critical success factors (CSFs) have found senior management involvement and commitment as a CSF in the implementation of lean six sigma projects [10]. Carleysmith et al. [70] and Mustapha et al. [10] noted that senior support as a critical factor that enables the process of LSS implementation. Mustapha et al. [10] also identified senior management supports as the most vital institutional factors which enable implementation of the LSS framework. Delgado et al. [71] says that the role of management is influencing the practice and guiding organizational culture to help the organization in closing the gap and proposing ideas for improvement.

According to Mustapha et al. [10] and Sharma [72] senior management involvement ensures the benefit of the program to the company by facilitating trust and communication. Senior management motivates to the team members, enables them to use procedures and methods for better quality. They also ensure recognition, which leads to effective and quicker change toward greater innovation [10]. Mustapha et al. [10] and Zu et al. [73] have also considered Management decisions and Organizational infrastructure in the lean critical success factors.

Näslund [68] frequently mentioned CSFs include the importance of a vision and strategy, top management support and commitment, importance of communication and information, and so forth. According to Mustapha et al. [10] linking business strategy with continuous improvement strategy is important. A clear and solid combination of LSS with the company's corporate strategy is the most critical factor for successful implementation.

Kumar et al. [74] and Mustapha et al. [10] note that stress on overall program success and short-term successes are important in the initial stages of LSS to ensure members' interest in the lean project. Apart from these LSS projects also need champion or sponsors who provide direction to the implementation team, find resources and plan for the project [10]. The readiness of the company is also a critical in lean implementation [10, 68, 75].

For the successful implementation of change effort, different education and training are also most required factors [68, 72, 74]. Education in a systems and process view of organizations answers the questions why the change of the system is needed, how it is supposed to change, and what the benefits will be to the system [68]. This education can also prepare the organization for change and create the readiness for change [68].

Customer satisfaction as the central goal of LSS, Cultural change and a transformation of attitudes of the employees [10, 74], productive teamwork [76], LSS working groups [74], duties and responsibilities of team players [74], Integration of LSS with the performance management process [10] and integration of human and process elements of improvement [10, 77] are the key element for the effective implementation of LSS programs. Because when these elements are combined with other aspects of LSS, it would produce its successful implementation in an organization.

2.8 Lean six sigma strategy

Lean Six Sigma combines the strategies of Lean and Six Sigma [30]. It has rapidly established itself as the key business process improvement strategy of

Deployment Strategy	Pros	Cons
Tops-Down Approach (Company Wide)	• Quick dissemination of knowledge • End to End projects • Large ROI	• Large initial Investment required • Higher Risk • Large Scope and Complexity
Partial Deployment	• Narrow Scope • Reduced Complexity • Easier to Navigate through organization – Change Management	• Narrow scope potentially sub-optimizes supply chain • Longer time to deploy • Smaller ROI
Focused Deployment	• Quick Wins • Address burning platforms	• Narrow scope potentially sub-optimizes supply chain • Smaller ROI

Table 3.
Lean six sigma deployment strategies. Source: [46].

choice for many companies [45]. In general, the approach has been to align Lean Six Sigma deployments with the strategy of the organization [46]. The strategy usually includes a plan that addresses the high level goals of the organization [46]. Strategic objectives are then broken down into routine metrics at the operational level. In classic Six Sigma terminology the "Big Y" is broken into "smaller y's" and plans are put in place to address each "small y" at the operational level. The majority of the companies use this approach in creating a Six Sigma portfolio that helps meet the strategic goals of the organization [46]. Both Lean and Six Sigma are key business process strategies which are employed by companies to enhance their manufacturing performance [78]. **Table 3** illustrates different deployment approaches that are used along with some of the pros and cons of using the approach [46].

Some companies use a top-down LSS deployment approach which is driven by strong governance [46]. For example: General Electric. This approach requires strong executive commitment and company wide acceptance to change [46].

The reasons for deploying LSS often include poor financial performance, retreating customer satisfaction, increased rivalry or the existence of a burning problem area [46]. There is not a single method that fits all Lean Six Sigma deployments. There are various deployment models that are broadly used in the industry today. **Figure 9** illustrates a deployment strategy that includes a few concepts presented above.

The strategy includes a pilot or proof of concept phase and ends with a companywide LSS deployment. In the pilot phase, specific problems are addressed to reveal the usefulness of the methodology and to gain buy-in. larger investments are made in infrastructure, education and training of yellow belts, green belts, black belts and master black belts [46]. Organizations must be aware of their toolset and enhancements needed to move forward. Many organizations train their Black belts on the theory of constraints and agile techniques to keep their toolset sharpened with a goal of including various manufacturing engineering methodologies. For truly successful LSS, the deployment must be tied into the strategy and be focused on the right parts of the business [46].

2.9 Assessment of lean six sigma readiness

Implementation of LSS is not a game of self interest. Thus, lean six sigma readiness must be assessed before its implementation in manufacturing organizations. Sreedharan et al. [79] recently designed an evaluation model in their quality paper

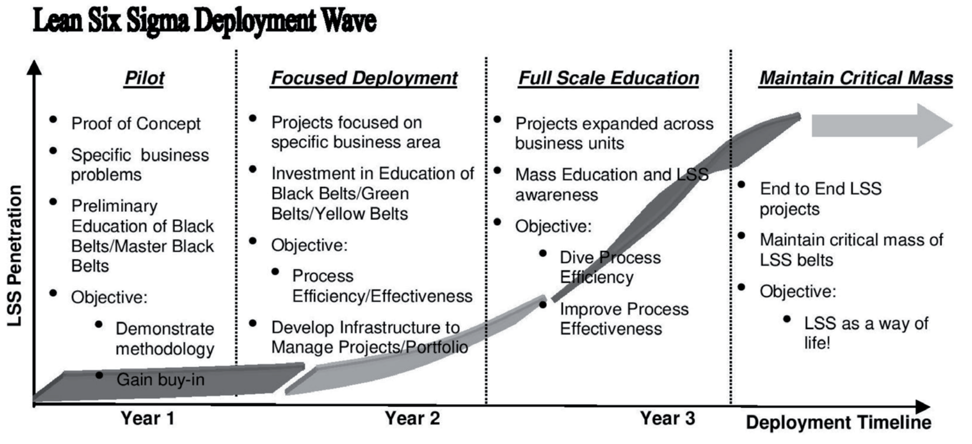

Figure 9.
Strategic goals and objectives in deployment wave. Source: [46].

"Assessment of Lean Six Sigma Readiness (LESIRE) for manufacturing industries using fuzzy logic". According to this evaluation model, the following criteria must be for readiness of LSS in manufacturing:

- Employee engagement
- Developing organizational readiness
- Establishing Lean Six Sigma dashboard
- Roadmap for project execution
- Infrastructure
- Top management commitment and Involvement
- Knowledge about Lean Six Sigma benefits
- Good leadership
- Clear vision and future plans
- Proper communication about future benefits expected from project by top management
- Experience in Lean Six Sigma deployment and implementation
- Lean Six Sigma facilitator Structure
- Alignment between the objective of the project and strategic objective of the company
- Customer focus
- Selection of candidate for Belt training
- Project prioritization

2.10 Implementation of lean six sigma in SMEs

Every organization is unique, without a common blueprint that universally applies. Lean Six Sigma implementation refers to a company's management philosophy and a long-term strategy [80]. It can be implemented in any SMEs in phases. The aim of implementation of LSS is finding wider application in many different environments. A successful implementation has several factors associated with it. Alkhoraif [80] has noted that Japanese automobile companies Toyota have a high implementation success rate due to their inflexibility in systematic planned management of employees, resources and equipment.

In a Lean Six Sigma SMEs, people deal with process improvement by conducting improvement projects as well as continuously improving daily routine. This requires an organization which understands the methodology.

According to Lokesh R, There are eight steps to a successful lean six sigma implementation in SMEs. Lokesh R is a certified Black Belt and general manager of process excellence at Firstsource Solutions Ltd. The first step in a Lean Six Sigma implementation is deciding to use the methodology. Once the leadership of a SMEs believes they can benefit from using Lean Six Sigma, they can follow eight steps—Step 1: Create a Burning Platform; Step 2: Put Resources in Place; Step 3: Teach the Methodology; Step 4: Prioritize Activities; Step 5: Establish Ownership; Step 6:

Figure 10.
Successful lean six sigma implementation steps source: Prepared by the author.

Take the Right Measurements; Step 7: Govern the Program; and Step 8: Recognize Contributions (**Figure 10**).

Step 1: Create a burning platform: SMEs must have a compelling reason for implementing Lean Six Sigma. For example "We are suffering huge quality losses; they account for more than 45 percent of our costs." and "Our competitors are gaining our market by 12 percent every quarter." Company leadership should become familiar with the burning platform, and understand how Lean Six Sigma can address the problems in the platform statement.

Step 2: Put resources in place: Do not hesitate to hire the right resource at right price. This is applicable to any resource, be it employees, material or technology. They must be able to work together as a team, and be empowered to carry out initiatives.

Step 3: Teach the methodology: For a lifetime survival, organizations need to train their team members to be powerful change agents. Yellow Belt, Green Belt and Black Belt training, along with skilled mentors, can help increase organizational awareness. The employees identified for training should share the organization's vision.

Step 4: Prioritize activities: Organizations must make a priority to: Listen to the customer, Identify critical-to-quality criteria and Ensure Lean Six Sigma efforts are linked to business goals. It is important to learn what to overlook and where to take risks. Activities must be assessed to ensure they are meeting the expectations of the organization's goals.

Step 5: Establish ownership: It must be clear who owns the Lean Six Sigma initiative. This may involve appointing a committee to find out who is responsible for the entire team. With ownership comes empowerment and a sense of pride, and team members who are more committed, accountable and engaged.

Step 6: Take the right measurements: What cannot be measured cannot be improved. By creating a measurement system, practitioners can determine baseline performance and use the data in objective decision making and analysis of variation. The key for measurement is to get the cost of quality right. Organizations also must find a way to measure process performance to ensure they receive data at a fast pace. Having too many items on a scorecard may shift practitioners' attention from the critical few metrics. They need to identify and measure the key leading indicators instead of measuring the many lagging indicators.

Step 7: Govern the program: A proper governance structure can help a program sustain momentum. Poor governance or too much governance can lead to the vision falling apart. Proper governance also helps practitioners create a best practice sharing forum, which helps projects to be replicated and can highlight common challenges. Without regularly scheduled, productive meetings or review sessions, the program can veer off course and employees may lack guidance.

Step 8: Recognize contributions: Rewards and recognition play a valuable role in making sure team members remain satisfied in their roles. They can help build enthusiasm for the program from a top-down and grassroots level. Rewards and recognition also can help drive innovation throughout the organization.

2.11 Significant barriers to implement LSS in manufacturing

Lean principles, tools and techniques have become a benchmark for manufacturing companies that have founded on the success of the Toyota Production System (TPS). Despite its popularity, companies are still struggling to achieve a successful lean implementation [81]. Many studies claim regarding the effectiveness of LSS in manufacturing and found that LSS practices is difficult and organizations encounter several roadblocks in this long continuous improvement journey. Some studies identified determining factors which make LSS journey either a success or a failure [82]. Existing research indicates some important organizational and technical barriers such as lack of management support and commitment, poor involvement of employees, and excessive confidence in lean tools and practices [81]. According to Navarro (a certified LSS Black Belt), there are five major barriers/obstacles/challenges to implement LSS in manufacturing:

- Insufficient management time to support lean
- Not understanding the potential benefits of applying lean
- Underestimating employee attitudes/resistance to change
- Insufficient workforce skills to implement lean
- Backsliding to the old inefficient ways of working

2.12 Significant benefits of LSS implementation in manufacturing

Many organizations have reported significant benefits after the implementation of LSS in manufacturing [79]. Lean and LSS is not just for manufacturing. It can benefit organizations of any size, in any industry. Because all organizations have problems to solve, all organizations have waste, and all organizations want to increase profits and reduce costs. It benefit to Healthcare, Financial services, Retail and hospitality, Education and Office-based businesses. LSS can also benefit organizations in Agriculture, Energy, Mining, Construction, Consulting, Design, Hotels, Travel and transportation, Law firms, Logistics, Government and Public services.

Albliwi et al. [35] has conducted a review research on LSS. They reviewed 37 LSS original research papers including 19 case studies had been published in the manufacturing sector in 11 different countries, which are: USA, UK, India, The Netherlands, China, Malaysia, Australia, Iran, Taiwan, Sweden and New Zealand. Albliwi et al. [35] identified more than 50 benefits (in 19 case studies). The top 10 benefits are:

1. Increased profits and financial savings;
2. Increased customer satisfaction;
3. Reduced cost;
4. Reduced cycle time;
5. Improved key performance metrics;
6. Reduced defects;
7. Reduction in machine breakdown time;
8. Reduced inventory;
9. Improved quality; and
10. Increased production capacity.

Other identified benefits are identifying different types of waste, development in employee morale toward creative thinking and reduction in workplace accidents as a result of housekeeping procedures.

Many other LSS practitioners, manufacturers, academic researchers have realized common benefits in manufacturing by applying a successful lean methodology are—Greater productivity, Smoother operations, Greater flexibility and responsiveness, Eliminates defects, Improved product quality, Reduced lead time, Increased customer satisfaction, Improved staff morale, Safer working environment and Boosts bottom line.

Ben Ruben et al. [61] identified that on successful deployment of the LSS framework in an Indian automotive component manufacturing organization, the internal defects was brought down to 6000 ppm from 16,000 ppm and environmental impacts was reduced to 33 Pt from 42 Pt.

Lean and Six Sigma offers a number of substantial benefits to organizations. Most importantly, Lean and Six Sigma Creates efficient processes so you can deliver more products to customers; Increases revenue by streamlining processes; Reduces costs by eliminating waste activities; Develops effective teams by empowering employees, staff morale and job satisfaction.

Singh and Rathi [28] have recently conducted a review research on LSS and covered papers from 2000 to 2018. They have selected a total of 216 research papers published in different countries on LSS implementation in various manufacturing sector such as automotive, micro small medium enterprises, health care, education, financial sectors etc. and observed major LSS benefits are: reduction in inventory; reduced costs of poor quality; improve customer highest satisfaction; reduced cycle time and lead time; defect free processes; and improvement in productivity.

2.13 Limitations of LSS in manufacturing

Many authors have argued that there are a significant number of limitations in LSS methodology. They have addressed many fundamental limitations [35]. These limitations can be a rich area for future research. The identified top seven limitations of LSS in the manufacturing sector are:

1. The absence of clear guidelines for LSS in early stages of implementation.

2. Lack of LSS curricula.

3. Lack of understanding of the usage of LSS tools and techniques.

4. Lack of a roadmap to be followed—which strategy first?

5. The limited number of practical applications of LSS integrated framework.

6. No globally accepted standards for certification.

7. Lack of expertise.

Thus, LSS practitioners need a clear guide for the direction of the early stages: which strategy should come first, Lean, Six Sigma or LSS, and what tools in the toolbox should be used first.

2.14 Lean and six sigma belts

A Lean and Six Sigma practitioner's "belt" refers to their level of experience. They may be a white, yellow, green, black, or master black belt. These roughly correspond to their hierarchy in martial arts.

Lean and six sigma master black belt—A highly experienced black belt.

Lean and six sigma black belt—Has expert knowledge of the DMAIC methodology, Lean methods and team leadership.

Lean and six sigma *green belt*—Has strong knowledge of the DMAIC methodology and Lean methods, but does not have experience with advanced statistical tools.

Lean and six sigma *yellow belt*—Has completed training in the fundamental concepts and tools of Lean and Six Sigma.

Lean and six sigma white belt—Has completed a small amount of Lean and Six Sigma awareness training.

2.15 Emerging trends in lean six sigma and agenda for future work

This study is the first comprehensive review of existing reliable literatures on different aspects of lean six sigma and the issues emerging in this field published during the period 1990 to 2019 and extract theoretical elements to develop the concept of LSS. The future of lean six sigma depends on the development needs of organization involved. These needs and opportunities are creating emerging trends in LSS which includes:

- The Big Data trend in lean six sigma
- Green lean six sigma
- Global Warming, Pollution and Lean's impact
- Lean and Six Sigma with environmental sustainability
- Lean's Impact on Resources
- Energy Conservation and management by LSS
- Factors affecting green lean six sigma
- Integration of LSS into educational systems.
- Assessment of LSS Readiness using fuzzy logic
- Green supply chain management

To encourage research in the field of lean six sigma and manufacturing, here we are highlighting gaps in the existing literature as a basis for developing a research agenda.

- Research gap 1 (performance measurement system for a particular organizations and processes);

- Research gap 2 (application of LSS in developing SMEs);
- Research gap 3 (integrated universal methods of manufacturing, frameworks, and models)

2.16 Successful LSS examples/stories in the manufacturing industry

As LSS was implemented world over for improving performances of various processes, developing countries have also started implementing LSS and got significant results in various sectors [83]. Lean Six Sigma (LSS) methodology was recently applied to an Auto ancillary conglomerate in India for achieving operational excellence. The root causes for the problem were identified and validated through data based analysis from LSS tool box. The application of LSS methodology resulted in reduction of drilling defects while machining injector bodies and reduced the Defects Per Million Opportunities from 38,000 to 5600. The application of this methodology had a significant financial impact (saving of about INR 1.4 million per annum) on the bottom-line of the company [83].

All type of manufacturing industry can increase profits, reduce costs and improve collaboration using LSS. For reference, below is Lean Six Sigma success examples in the Manufacturing industry organized systematically (**Table 4**).

General Electric	**Dell India Pvt. Ltd.**	**NALCO**
Xerox	Colgate Palmolive	Steel Authority of India
Ford	Al fanar	HP
Toyota	Alessa	Seimens
Durgapur Steel	Zuari Agrochemicals	3 M (American MNC)
BEML (Bharat Earth Movers)	Brother Gas	Acme Industries
ADCO (Abu Dhabi oil Company)	Gulf Gas	AEDC
AMRDEC	Wabash National Corp.	Gooch & Housego
Axalta Coating Systems	Fortress Paper	Ingersoll Rand
Barcoding Inc.	General Cable	Jabil Shanghai
Beverage Producers	GKN Sinter Metals	John Sisk & Son
Bosch	Milling Products	KushCo Holdings, Inc.
Celestica	Molded Devices, Inc.	Foster Threaded Products
Cummins	Real Alloy	Seegrid
Luvata	Reliable Plant	Spanbild
MC Assembly	Santana Textiles	The Jubach Company
Magline	Think Lightweight	The National Productivity Centre of Nigeria
Masonite	Topper Industrial	UTC Aerostructures
Metform Engineers	Universal Machining Industries Inc.	Vermeer Corp.

Source: Prepared by author (adopted from [84]).

Table 4.
Lean six sigma success examples in the manufacturing industry.

2.17 Conclusions and suggestions

Lean Six Sigma is a combination of two powerful process improvement methods: Lean and Six Sigma. It decreases organization's costs by removing "Waste" from a process and solving the problems caused by a process. Lean Six Sigma (LSS) is an emerging extremely powerful technology which is used to identifying and eliminating waste, improving the performance, efficiency and customer satisfaction to sustain in competitive manufacturing and nonmanufacturing environment. The focus of this chapter was to explore the each aspect of LSS in manufacturing. This systematic comprehensive review aims to synthesize, organize and structure the stock of knowledge relating to Lean Six Sigma and manufacturing. The identified lean six sigma tools and techniques, methodologies, frameworks, success and failure factors and strategies can be effectively used as a roadmap in manufacturing sector. This is also identified that the LSS has been implemented worldwide and in all type of manufacturing organizations for achieving the excellence. They have been successfully achieved their LSS objectives. But there are various challenges and barriers have been identified in the deployment of LSS. Assessments of lean six sigma readiness and implementation steps are most important that every practitioner must be aware. Basics of lean six sigma are discussed to get the root causes by in-depth understanding of the fundamentals of Six Sigma.

To bring lean in the organizations, every manager must be master and implement the eight basics of Lean Six Sigma for manufacturing. They should achieve their goal of satisfying/delighting customers by delivering higher quality service in less time by improving related business processes, eliminating defects and focusing on how the work flowed through the process.

This can be achieved only if the creativity of the people is used in team work on the processes with data and with an understanding of customers and processes. Therefore, the team members should work together to create real solutions for the organization. They should be from the different process areas, and their decisions should be based on data and facts.

Furthermore, for future direction, research and practitioners can be more focused on prioritization of significant barriers as identified in chapter and to tackle them during LSS implementation in manufacturing so that continuous improvement can be easily achieved [1].

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