Comprehensive Research and Reviews in
Engineering and Technology
Journal homepage: https://crrjournals.com/crret/
ISSN: 2961-3639 (Online)

(RESEARCH ARTICLE)

Enhancing manufacturing excellence through lean six sigma

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Comprehensive Research and Reviews in Engineering and Technology, 2022, 01(01), 029–044

Publication history: Received on 05 August 2022; revised on 13 September 2022; accepted on 17 September 2022

Article DOI: https://doi.org/10.57219/crret.2022.1.1.0025

Abstract

Lean Six Sigma (LSS) is one of the most popular and widely used business improvement methodologies. The integration of LSS is important as Lean focuses on eliminating waste between and within the steps of the process, and Six Sigma works to reduce the variation of output seen in processes and works to improve the quality of the inputs going into the process. This research provides a detailed view for practitioners of applying LSS in manufacturing. This study explores the latest developments, current trends and perspectives of LSS. LSS critical success factors (CSFs) in manufacturing are discussed. The success of LSS has been attributed a lot to the leadership. An integrated LSS-DMAIC framework is developed for improving process efficiency and effectiveness. The proposed framework is a practical roadmap of LSS which can be utilized in any manufacturing sector. Finally, this work can serve as a foundation for future efforts in an attempt to improve the classification and contents in ways that better describe researchers in the field of LSS.

Keywords: LSS; DMAIC; Lean Manufacturing; Six Sigma; Process Improvement; TQM.

1. Introduction

Lean Six Sigma (LSS) approach combines Lean manufacturing and six sigma techniques. LSS is a systematic approach that focuses on continuous process improvement, reducing process waste, and increasing process efficiency and effectiveness. As shown in Fig. (1), process efficiency is the ratio of outputs to inputs, or how well a process uses its resources to achieve its goals. Process effectiveness is the degree to which a process meets its intended outcomes, or how well a process satisfies its customers or stakeholders. Lean Six Sigma (LSS) is an approach for implementing TQM. LSS is a continuous improvement approach that aims to improve process efficiency and effectiveness. LSS is a customer focused improvement strategy. Fig. (2) shows the difference between lean and six sigma. LSS is a process continuous improvement approach that aims to improve process efficiency and effectiveness. LSS focuses on improving quality, reducing process variation, and eliminating activities that do not add value. LSS is a methodology that integrates Lean Manufacturing and Six Sigma strategies, which means that the principles, philosophies and tools of both methodologies are also united in one approach. LSS allows manufacturing process to become more efficient and effective in maintaining continuous improvement. As shown in Fig. (3), LSS framework follows the traditional Six Sigma steps of the DMAIC roadmap (Define, Measure, Analyze, Improve, Control). Fig. (4) and Table (1) show the most common LSS tools., Gomaa, 2023, [14] and Gomaa, 2023, [15], Barbosa, 2023, [8], Bajic, 2023, [7], Caballero-Morales, 2023, [9], Francescatto, 2023, [13], Tsarouhas, 2023, [49].

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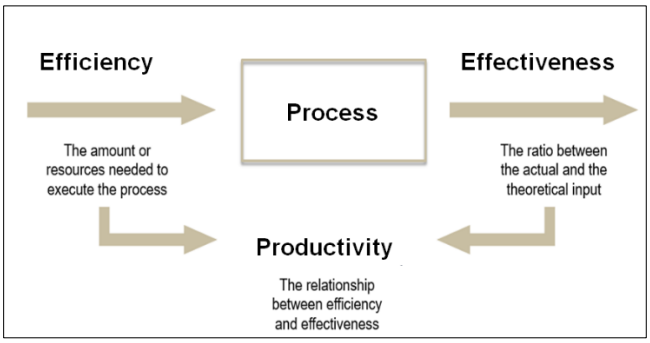

Figure 1 Process effectiveness and efficiency

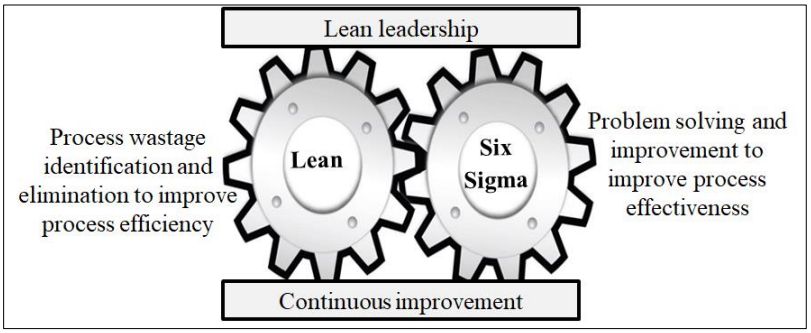

Figure 2 Core objectives of LSS

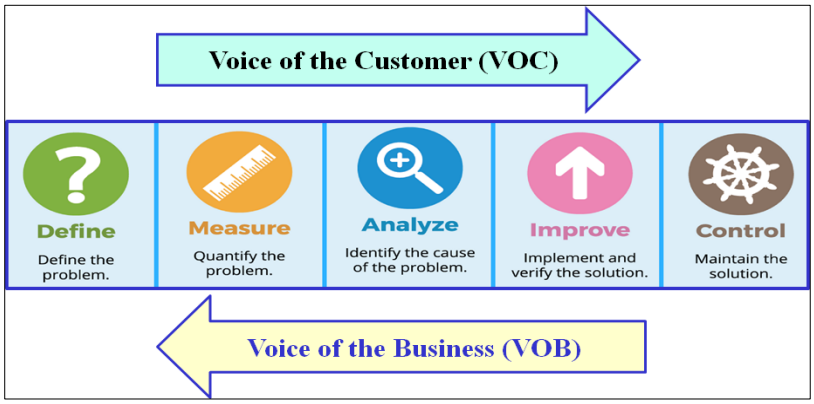

Figure 3 LSS-DMAIC Framework

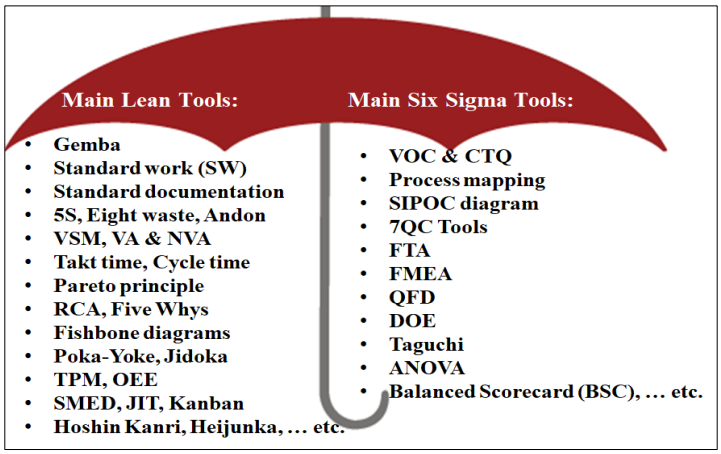

Figure 4 Most common LSS tools

Table 1 Most common LSS tools in manufacturing domain

Tool Symbol	Tool description
5S / 6S	Visual control
5Why	5 Whys analysis
7QC	7 Quality control tools
8Waste	Lean 8 waste analysis
ABC	Pareto classification analysis
ABC-XYZ	Advanced classification analysis
Actions	Improvement Actions
Andon	Visual control device
ANOVA	Analysis of variance
Brainstorming	Brainstorming group creativity technique
Benchmarking	Internal and external benchmarking & best practices
Bottleneck	Bottleneck Analysis
C&E	Cause–effect diagram
CBA	Cost-benefit analysis
Charter	Project charter
Charts	Process control charts
COPQ	Cost of poor quality
Cpk	Process capability analysis
CSA	Customer satisfaction analysis
CTQ	Critical to quality
CTT	Critical to time
DMAIC	Define-Measure-Analyse-Improve-Control cycle
DMADV	Define-Measure-Analyse-Design-Validate
DPMO	Defects per million opportunities

Tool Symbol	Tool description
DOE	Design of experiments
Fishbone	Fishbone Diagram
FMEA	Failure mode effect analysis
Gage R&R	Gage Repeatability and Reproducibility
Gantt	Gantt Chart
Gemba	Go and see for yourself
Heijunka	Levelling of work flow
JIDOCA	Automatic Detection
JIT	Just in time
Kaizen	Kaizen events
Kanban	Kanban board
KANO	KANO model
KPIs	Key performance indicators dashboard
Mapping	Process mapping (flow chart, SIPOC, Spaghetti diagram, etc.)
Network	Network diagram
OEE	Overall Equipment Effectiveness
Pareto	Pareto chart
PCE	process cycle efficiency
PDCA	Problem solving cycle (Plan-Do-Check-Act)
Poka-Yoke	Mistake Proofing
QFD	Quality function deployment
RACI	Responsible, Accountable, Consulted, Informed
RCA	Root cause analysis
SIPOC	Suppliers, Inputs, Process, Outputs, and Customers
SMART	SMART goals
SMED	Single-minute exchange of die
SW	Standard work
Taguchi	Taguchi method
Takt	Takt Time
TQM	Total quality management culture
TPM	Total productive maintenance
VAA	Value-added analysis
VOB	Voice of business
VOC	Voice of customer
VOP	Voice of process
δL	Sigma level

2. Literature review

There are a number of ways that companies have used LSS methodology to improve the performance, the most important of which are: Gomaa, 2023, [14] and Gomaa, 2023, [15], Almaz, 2023, [3], Crowdle, 2023, [11], Nelson, 2023, [30], Antony, 2020, [6], Ishak, 2020, [21], Alarcón, 2023 [1], Guimarães, 2023, [16], Huang, 2023, [20], Madhani, 2020, [25], McDermott, 2023, [26], Orji, 2022, [32], Reyes, 2023, [34], Singh, 2023, [40], Sisman, 2023, [41], Sundram, 2023, [43], Tay, 2021a, [44]:

- Reducing wastes - Reducing the eight lean wastes that can impact the process is one of the central goals of the LSS methodology.
- Decreasing defects - LSS was originally developed to eliminate defects in manufacturing and reduce them within acceptable limits.
- Preventing errors - Any process that is losing efficiency because of a high error rate in the system is a prime candidate for LSS improvement. Poka-Yoke tool prevents mistakes by forcing the user to do a task one way. Also, 5S tool reduces errors that interrupt the process efficiency by providing a clean, safe, efficient, and uncluttered environment.
- Reducing delays - Improving process flow and reducing disruptions contribute to reducing delays in the process and enhancing on-time delivery.
- Decreasing lead times - Streamlining processes leads to shorter lead times, allowing faster response to customer requirements and market changes.
- Improving order fulfillment - This is measured by the percentage of orders that meet delivery performance with complete and accurate documentation and no delivery damage. The LSS methodology can help maximize demand fulfillment by identifying where potential problems lie.
- Reducing order fulfillment cycle time - LSS review of a company's order fulfillment system helps identify issues that need to be addressed. This review is likely to conclude that some clear improvements are in order. Improvement may require system integration, automated picking, automated shipment planning, automated verification of shipments, and reduced paperwork.
- Improving resource productivity & Value-added - By reducing defects, reducing waste, and improving time utilization, LSS helps improve resource productivity and value-added ratio.
- Reducing product costs - By eliminating inefficiencies and improving resource productivity, LSS helps cut operational costs significantly, leading to improved profitability.
- Improving customer satisfaction - Improving quality, on-time delivery and product cost contribute to increased customer satisfaction, thus enhancing the company's reputation.
- Creating a competitive advantage - Based on the above benefits, applying LSS principles to any organization's supply chains can create competitive advantage.
- Effective problem solving: LSS equips processes with tools to identify root causes of issues and implement lasting solutions, ensuring continuous improvement.
- Improving employee morale - When LSS is implemented successfully, it will empower employees and boost morale.

The manufacturing sector faces various challenges in optimizing its resources to achieve higher productivity. The most common manufacturing problems include high cycle time, high defect rates, high resource waste, high inventory cost, etc. Therefore, it is important for an organization to develop critical success factors that help overcome these problems.

Critical success factors are the actions and processes that must be controlled by the management during the implementation of a LSS project. The success of LSS is not entirely tied to applying the right tools and methods but on knowing the critical success factors and obstacles that must be over-come. Critical success factors are the elements required for an organization or project to achieve its mission. Based on the literature review, it was found that the most important critical success factors for LSS are as shown in Table (2)., Gomaa, 2023, [14], Gomaa, 2023, [15], Samanta, 2023, [35], Ali, 2020, [2], Yazdi, 2020, [51], Houti, 2019, [19], Selvaraju, (2019), [38].

Table 2 LSS critical success factors (CSFs)

#	Perspective	Factors	[14]	[15]	[35]	[2]	[51]	[19]	[38]
1	Managerial factors	Management support, commitment and involvement	x	x	x	x	x	x	x
		Leadership development and awareness	x	x		x	x	x	
		Clear strategic plan, business plan, vision and mission			x		x	x	x
		Effective external and internal benchmarking of best practices		x					
		Clear goals, objectives, policies, and KPIs		x	x				
		Information quality and sharing			x				x
		Focus on competitive priorities			x				
		Effective teamwork management					x		
2	Customer factors	Customer engagement and satisfaction						x	
		Effective customer relationship management (CRM)						x	
4	HRM factors	Effective Organizational structure & responsibility matrix	x	x	x		x	x	
		Employee training, education and awareness	x	x	x	x	x	x	x
		Employee attitude, skills and expertise					x	x	
		Effectives reward, recognition and motivation system		x			x	x	
5	IT factors	Effective information and communication technology	x	x	x	x	x	x	x
		IT Infrastructure						x	
		Effective LSS software						x	
6	Facility factors	Effective facility layout, configuration and planning		x					
		Effective project selection, planning and control system	x	x	x	x	x	x	x
		Effective facility resources and infrastructure				x		x	
7	Continuous improvement factors	Understanding LSS methodology, techniques and tools	x	x				x	x
		Standardization of procedures and information							x
		Linking LSS tools to business strategy							x
		Linking LSS tools to supply chain							x
		Employee engagement, empowerment and satisfaction	x	x			x		
		Project success stories, best practices and benchmarking					x		x
		Effective change management and Organizational culture	x	x	x	x	x	x	

8	Financial factors	Financial resource capabilities			x	x	x	x	x
		Economic benefits			x				

Several studies have focused on the applications of LSS in manufacturing domain. Table (3) presents a comprehensive survey of LSS studies, and they are classified based on contribution, application, main objectives and main LSS tools. In conclusion, the main findings of the previous literature review (from [1] to [51]) indicate that applying the LSS approach can improve quality, reduce process variation, eliminate waste, improve production rate, improve process productivity, reduce cycle time, reduce non-value-added time, reduce lead time, reduce production cost, reduce unit price, and increase customer satisfaction.

Table 3 LSS studies in manufacturing domain (2020 to 2023)

#	Ref.	Contribution	Application	Main objectives	Main LSS Tools
[4]	Altug, 2023	Discussed a six-sigma framework for manufacturing	A case study in a spare parts company in Turkey	Improving process performance Reducing lead time	DMAIC, Mapping, δL, R&R%, ANOVA, FMEA, RCA, C&E
[5]	Andronicean u, 2023	Developed a Kaizen framework for increasing energy efficiency	A case study in a refrigerating company	Increasing energy consumption performance	DMAIC, Layout, Mapping, 5S, Kaizen, 8Waste
[10]	Conde, 2023	Discussed a LSS framework for manufacturing	A case study in a manufacturing car parts supplier	Reducing process defects	DMAIC, Charter, Mapping, CTQ, Charts, Pareto, Process capability, RCA, C&E
[12]	Enache, 2023	Developed a LSS framework for manufacturing	A case study in a metal door manufacturing	Reducing scrap rate	DMAIC, Charter, Mapping, CTQ, VOC, R&R%, Charts, Pareto, RCA, C&E
[17]	Habib, 2023	Discussed a lean framework for manufacturing	A case study in a labelling and packaging manufacturing	Reducing lead time Improving OEE	DMAIC, Charter, Mapping, VSM, 5S, charts, RCA, C&E
[22]	Jiménez-Delgado, 2023	Developed a LSS framework for manufacturing	A case study in a Textile Sector	Improving quality Reducing lead time	DMAIC, Charter, Mapping, VSM, 5S, charts, Process capability, RCA, C&E
[27]	Mittal, 2023	Discussed a six-sigma framework for manufacturing	A case study in a rubber weather strips company	Reducing rejection rate Reducing cost	DMAIC, CTQ, Mapping, Pareto, C&E, 5S, CBA.
[31]	Oliveira, 2023	Discussed a lean framework for manufacturing	A case study in an automotive parts assembly line	Reducing setup time	Mapping, 8Waste, SMED, Gemba, SW, charts, Pareto, C&E
[36]	Sasikumar, 2023	Developed a LSS framework for manufacturing	A case study in a bias tyre manufacturing	Reducing waste Improving OEE	DMAIC, Mapping, OEE, charts, Pareto, RCA, C&E
[37]	Satolo, 2023	Developed a LSS framework for manufacturing	A case study in milking processes	Reducing defect Reducing cost	DMAIC, Mapping, VSM, RCA, C&E, PDCA,

#	Ref.	Contribution	Application	Main objectives	Main LSS Tools
[42]	Srinivasan, 2023	Discussed a LSS framework for manufacturing	A case study in steel industry	Reducing non-value-added time Reducing lead time	DMAIC, Mapping, Charter, VSM, Pareto, RCA, C&E,
[47]	Toki, 2023	Proposed a LSS - Quick Changeover - framework for manufacturing	A case study in ready-made garments (RMG) industry	Improving Process cycle efficiency Reducing cost	Mapping, SMED, RCA, C&E
[48]	Trubetskaya, 2023	Developed a LSS framework for manufacturing	A case study in a compound animal feed manufacturing	Reducing inventory stock Reducing lead time	DMAIC, Mapping, VSM, Pareto, SW, PCC
[49]	Tsarouhas, 2023	Discussed a six-sigma framework for manufacturing	A case study in a packaging olives production	Minimizing defects & variance Reducing production cost	DMAIC, charter, Mapping, CTQ, Benchmarking, Pareto, DOE, Process capability, RCA, C&E
[50]	Utama, 2023	Developed a sustainable LSS framework for manufacturing	A case study in producing carrageenan in Indonesia	Improving Manufacturing Sustainability Index (MSI)	DMAIC, Mapping, CTQ, VSM, FMEA, RCA, C&E
[39]	Sharma, 2022	Proposed a LSS framework for manufacturing	A case study in an automobile manufacturing	Reducing defect Increasing production rate	DMAIC, Mapping, Charter, VSM, 8Waste, Pareto, C&E, δL
[23]	Kumar, 2021	Developed a LSS framework for manufacturing	A case study in an engine cylinder company	Reducing defect Increasing sigma level.	DMAIC, Charter, Mapping, ABC, Pareto, Charts, C&E
[18]	Hardy, 2021	Presented a LSS framework for manufacturing	A case study in laminated panel production	Reducing downtime Improving OEE	DMAIC, Charter, Mapping, CTQ, Takt, VSM, OEE, Charts, C&E, PDCA, FMEA.
[28]	Murmura, 2021	Developed a LSS framework for manufacturing	A case study in iron industry	Reducing lead time Reducing defect	DMAIC, Charter, Gantt, Mapping, VSM, δL, Charts, 5Why, C&E
[33]	Patyal, 2021	Proposed a six-sigma framework for manufacturing	A case study in a chemical company	Reducing customer complaints	DMAIC, Charter, Mapping, Cpk, 5Why, C&E
[24]	Liu, 2020	Presented a VSM framework for manufacturing	A case study in footwear manufacturing	Reducing defect Reducing lead time	DMAIC, VSM, Takt, DOE, Taguchi
[29]	Nandakumar, 2020	Developed a LSS framework for manufacturing	A case study in food industry	Improving process OEE	DMAIC, Mapping, VSM, OEE, ANOVA, 5S, C&E
[46]	Tiwari, 2020	Proposed a sustainable lean production framework	A case study in cookware manufacturing	Improving sustainability Minimizing safety incidents	DMAIC, Charter, KPIs, VSM, Pareto, 8Waste, C&E

3. Proposed LSS framework

Based on the analysis of the literature review, Table (4) shows the most common LSS objectives in manufacturing domain and the appropriate LSS tools to achieve these objectives. Table (5) shows the process lean (DWONTIME) waste analysis and appropriate LSS tools to overcome this waste. Table (6) shows the main resources, main objectives, main problems, and appropriate LSS tools to improve resource productivity.

Table 4 LSS objectives and Tools in manufacturing processes.

#	Perspective	LSS Objectives	LSS Tools
1	Customer	Improving customer satisfaction	VOC, CSA, SW, QFD, 5WA, C&E
2	Production Management	Improving production rate Reducing non-value-added Reducing cycle time Improving resource productivity: - Improving labor productivity - Improving material productivity - Improving machine productivity - Improving energy productivity, … etc. Improving machine availability Improving overall equipment effectiveness (OEE) Reducing work in process (WIP) Improving time utilization	PM, 5S, VSM, TPM, OEE, SW, Kanban, 5WA, C&E
3	Quality Management	Improving quality % Improving sigma level Reducing rework time	VOC, CTQ, CC, δL, 5S, PC, ABC-XYZ, SW, QFD, 5WA, C&E

Table 5 Process Lean wastes (DWONTIME) analysis and LSS Tools

#	Waste Type	Waste Description	Root Cause	LSS Tools
1	Defects	Produce defective products or need to be rectified.	Lack of motivation	Pareto chart Cause–effect diagram
2	Waiting	Waiting for materials Waiting for handling	Poor coordination	VSM TPM
3	Over-Production	Produce more than the customer demanded	Poor production planning	Production planning Standard work
4	Not Utilizing Talent	Lose time, ideas, skills by ignoring employee ideas	Resistance to change	Advanced training Motivation program
5	Transportation of materials	Unnecessary transportation of materials	Poor housekeeping	5S (Visual control) VSM
6	Inventory Excess	Over stock of raw materials, WIP and final products	Poor material planning	Material classification Material planning
7	Motion of people	Perform unnecessary movements for work	Poor housekeeping	5S (Visual control) Standard work
8	Excess Processing	More work or higher quality than required	Lack of standardization	Standard work Advanced training

Table 6 Process resource analysis and LSS Tools

#	Main Resources	Main objectives	Main problems	LSS Tools
1	Manpower	Improving labor productivity	- Lack of training & education - Lack of motivation - Lack of Kaizen culture	- Visual control (5S) - Material classification - Material Defect Analysis
2	Method	Improving work Saudization	- Lack of process planning - Lack of standardization - Lack of objectives & KPIs	- QA / QC check list - Standard procedure & doc. - Standard time analysis
3	Machine	Improving machine productivity	- Equipment breakdown - Low performance rate - Limited equipment	- Check machining parameters - Process time analysis - Value added time analysis
4	Materials	Improving material productivity	- Low material quality - Lack of material control - Poor storage conditions	- KAIZEN training program - Advanced training program - Update motivation program
5	Measurement	Improving measurement system efficiency	- Inefficient inspection tools - Lack of statistical tools - Lack of tools calibration	- Accuracy of inspection tools - Sampling size and analysis - Auditing system
6	Management System	Improving work Saudization	- Lack of KPIs dashboard - Lack of knowledge about LSS - Lack of benchmarks	- Internal & external benchmarking - KPIs dashboard - Standard information - Standard Templates
7	Environmental	Improving working conditions	- Unsafe working conditions - Lack of safety PPE - Lack of safety audit	- Visual control (5S) - Improve working conditions - Job hazard analysis (JHA)
8	Time	Improving time utilization	- Lack of standardization - Lack of process planning - Lack of objectives & KPIs	- Visual control (5S) - Standard time analysis - Standard procedure & doc.

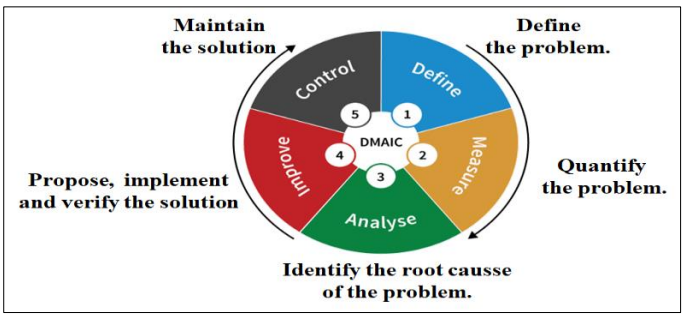

Figure 5 LSS DMAIC Cycle

The primary objective of this section is to propose a roadmap for LSS leadership to improve the project effectiveness and efficiency. Based on in-depth analysis of the literature review, LSS framework was developed using various analysis and improvement tools. As shown in Fig. (), DMAIC (Define, Measure, Analyze, Improve and Control) methodology used in LSS is a disciplined and structured process used in solving project problems and achieving continuous improvement. If there is a problem in the process that prevents the project from producing high-quality products and services efficiently and consistently within the specified time and at low cost, LSS-DMAIC tools help identify the root cause of the

defects. Table (7) shows the proposed LSS-DMAIC framework for project management. Details of the DMAIC framework are provided in the following subsections.

Define Phase: Studying process, product and problems in detail:

1.Defining the project goals, objectives and scope of work:
- Clearly define the goals and objectives of the LSS project.
- Identify the specific processes that need improvement.
- Define the scope of the project, including key deliverables and success criteria.

2. Building a cross-functional team:
- Form a team with members from different departments involved in product and processes.
- Ensure that the team has a mix of skills, including process knowledge, data analysis, and problem-solving.

3. Define product description and required processes.
4. Defining current situation (SWOT analysis)
5. Defining process problems and targets
7. Creating a project charter & a project plan
7. Understanding and identifying the customer requirements:
- Identify and understand the requirements and expectations of customers.
- Using tools like VOC analysis to capture customer feedback and incorporate it into improvement goals.
- Identify CTQ for the final product or service.

8. Mapping the current state process:
- Create a detailed process map (process flow chart, SIPOC, … etc.) that outlines the current state of the processes.
- Identify key inputs, processes, outputs, and stakeholders involved in each step of processes.

9. Identifying Key Metrics:
- Determine key performance indicators (KPIs) that align with the objectives.

Measure Phase: Designing and collecting the required information:

10. Designing standard templates & collecting the required information:
11. Measuring current performance evaluation, KPIs related to product and process, such as lead times, cycle times, resource productivity, inventory levels, and defect rates.
12. Measuring sigma level & process capability
13. Preparing current value stream mapping
14. Measuring process wastes & defects

Analyze Phase: Applying analysis tools and identifying root causes:

15. Using appropriate statistical analysis tools and techniques to analyze the collected information and identify areas for improvement.
16. Analyzing process defects
17. Analyzing of process variance
18. Analyzing critical to quality (CTQ)
19. Analyzing process wastes & bottleneck
20. Analyzing process parameters
21 Conducting root cause analysis (RCA) and fishbone diagrams.
22. Determining improvement recommendations

Improve Phase: Implementing solutions according to priorities:

23. Identifying and prioritizing opportunities for improvement:
- Conduct a thorough analysis to identify bottlenecks, waste, and inefficiencies in the processes.

- Prioritize improvement opportunities based on their impact on customer satisfaction and overall process performance.

24. Preparing the improvement plan
25. Training the teamwork groups
26. Implementing kaizen & lean principles: Applying lean principles to eliminate waste and improve flow within the process. This may include:
    - Reducing excess inventory through JIT practices.
    - Implementing visual management to enhance transparency and communication.
    - Streamlining processes to minimize unnecessary steps and delays.
27. Applying six sigma techniques: Using Six Sigma techniques to address variations and defects in the processes. This may involve:
    - Conducting root cause analysis to identify and address the underlying causes of defects.
    - Implementing statistical process control to monitor and control process variability.
    - Utilizing DMAIC methodology for continuous improvement.
28. Implementing changes and monitoring progress:
    - Pilot test the proposed changes on a small scale.
    - Gather feedback and make adjustments as needed.
    - Implement the identified improvements.

Control Phase: Monitoring the process and achieving daily improvements:

29. Developing and implementing a control plan
30. Designing and document standard practices
31. Following process control charts
32. Following quality assurance / quality control (QA/QC) checklists
33. Following Kaizen improvement
34. Establishing KPIs and control mechanisms to monitor the process efficiency and effectiveness.
35. Establishing Before / after analysis, continuously track and report progress to ensure sustained improvements.
36. Creating a culture of continuous improvement:
    - Foster a culture of continuous improvement within the organization.
    - Encourage feedback from employees involved in the product and processes, and empower them to identify and address issues proactively.
37. Documenting and standardizing processes:
    - Document the improved processes and create standard operating procedures.
    - Ensure that the standardized processes are communicated and followed consistently across the organization.
38. Providing training and support:
    - Train employees on the new processes and methodologies.
    - Provide ongoing support and resources to maintain a focus on continuous improvement.
39. Preparing project close-out report
40. Communicating results & learned lessons:
    - Share the results and successes of the LSS project with stakeholders.
    - Highlight the impact on key metrics and overall supply chain performance.

Table 7 Proposed LSS-DMAIC framework for manufacturing processes.

Phase	Objectives	Key Activities	Used Tools
Define	Studying process, product and problems in detail.	Defining the goals, objectives and scope of work	Brainstorming
		Building teamwork & developing project charter	Brainstorming
		Defining product description and required processes	Brainstorming
		Defining current situation (strength & weakness)	Gemba walk SWOT matrix

		Defining process problems and targets	Brainstorming
		Create a project charter & a project plan	Charter
		Defining customer requirements & CTQ factors	CTQ and VOC
		Defining process mapping (flow chart, SIPOC)	SIPOC
		Identifying key metrics	KPIs
Measure	Designing and collecting the required information.	Designing standard templates & collect information	Brainstorming
		Measuring current performance evaluation	KPIs
		Measuring sigma level & process capability	Sigma level, Cpk
		Preparing current value stream mapping	VSM
		Measuring process wastes & defects	8 Lean wastes
Analyse	Applying analysis tools and identifying root causes	Using appropriate statistical analysis tools	7QC
		Analysing process defects	Pareto chart
		Analysing process variance	ANOVA
		Analysing critical to quality (CTQ)	SPC & 7QC
		Analysing process wastes & bottleneck	RCA
		Analysing process parameters	DOE
		Conducting RCA and fishbone diagrams	C&E diagram
		Determining improvement recommendations	Brainstorming
Improve	Implementing solutions according to priorities	Identifying and prioritizing opportunities for improvement	Brainstorming
		Preparing the improvement plan	Brainstorming
		Training the teamwork groups	Advanced training program
		Implementing kaizen & lean principles	5S, SW, … etc.
		Implementing six sigma principles	7QC
		Implementing changes and monitoring progress	Brainstorming
Control	Monitoring the process and achieving daily improvements	Developing and implementing a control plan	Brainstorming
		Designing and document standard practices	QA/QC
		Following process s control charts	Control charts
		Following QA/QC checklists	QA/QC
		Following Kaizen improvement	Gemba walk, Kaizen, 5S, SW
		Following KPIs, Sigma level, process capability, …	KPIs dashboard
		Before / after analysis	KPIs analysis
		Creating a culture of continuous improvement	Gemba walk
		Documenting and standardizing processes:	Auditing
		Providing training and support	Brainstorming

		Preparing project close-out report	Brainstorming
		Communicating results & learned lessons	Brainstorming

4. Conclusion

This research provides a detailed view for practitioners of applying LSS in manufacturing. Based on a literature review, Lean Six Sigma (LSS) promotes benefits in reducing waste, improving quality, increasing productivity, reducing costs, and improving customer satisfaction. This study explored the latest developments, current trends and perspectives of LSS in the context of the manufacturing sector. This work identified the scope of LSS implementation and critical success factors. Essentially, LSS success factors are influenced by leadership, training, human resource management as well as customer relationship management. This study proposed LSS-DMAIC framework to improve manufacturing efficiency and effectiveness. The proposed framework is a practical roadmap of LSS which can be utilized in any manufacturing sector. Finally, this work provides positive evidence regarding the effects of LSS tools and techniques on the performance of organizations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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