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Improving Manufacturing Efficiency and Effectiveness Using Lean Six Sigma Approach

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Abstract: Success of any organization is directly related to how effectively it implements continuous improvement methodologies. Lean Six Sigma (LSS) is a continuous improvement approach that aims to improve process efficiency and effectiveness. This study explores the latest developments, current trends and perspectives of LSS in the manufacturing sector. LSS critical success factors (CSFs) in manufacturing are discussed. The results of this study revealed the most important contributions in terms of publications, authors, countries, application, objectives and LSS tools. The results found that, applying LSS approach can improving quality, reducing process variation, eliminating waste, improving production rate, improving process productivity, reducing cycle time, reducing non-value-added time, reducing lead time, and reducing production cost. Which lead for reducing unit price and increasing customer satisfaction. Furthermore, the results can be used for a systematic literature review by researchers and manufacturing leaders before embarking on a continuous improvement journey. Finally, an integrated LSS-DMAIC framework is developed for improving manufacturing efficiency and effectiveness.

Keywords: *LSS, SCM, LSS-SCM, Supply chain improvement, TQM, manufacturing*

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I. INTRODUCTION

Process improvement is a methodology within total quality management (TQM), specifically in manufacturing. Its aim is to always be improving the 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 for total quality management (TQM) implementation. 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). Table (1) shows the most common LSS tools. Table (2) shows proposed LSS-tools in different steps of DMAIC methodology., [1], [2],[3].

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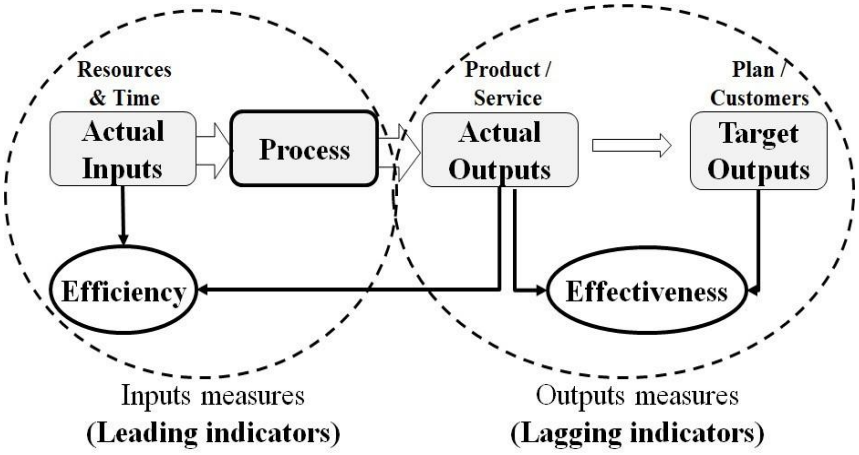

Fig. 1. Process effectiveness and efficiency.

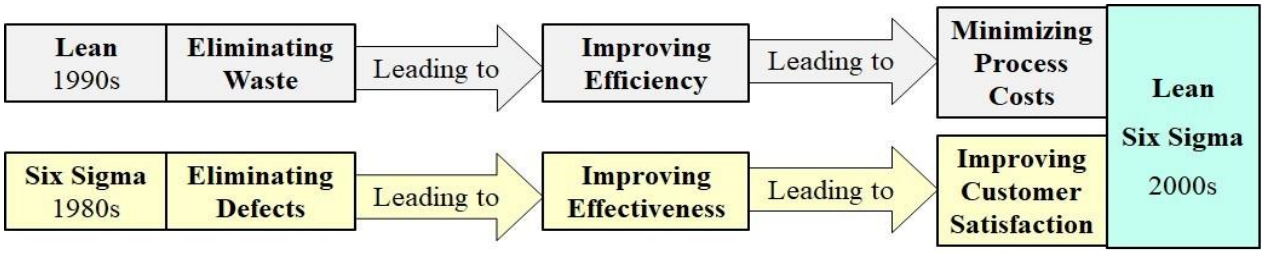

Fig. 2. Core objectives of LSS.

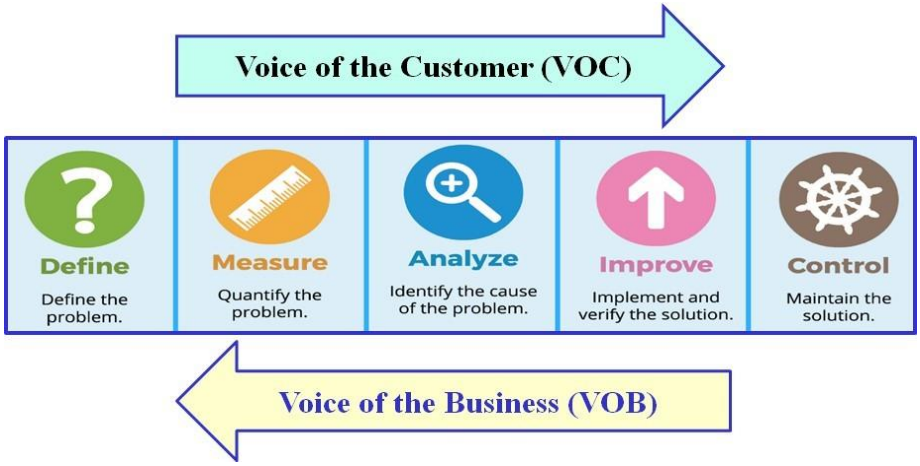

Fig. 3. DMAIC framework.

TABLE 1
MOST COMMON LSS TOOLS IN MANUFACTURING DOMAIN

#	Tool Symbol	Tool description
1	5S / 6S	Visual control
2	5Why	5 Whys analysis
3	7QC	7 Quality control tools
4	8Waste	Lean 8 waste analysis
5	ABC	Pareto classification analysis
6	ABC-XYZ	Advanced classification analysis
7	Actions	Improvement Actions
8	Andon	Visual control device
9	ANOVA	Analysis of variance
10	Brainstorming	Brainstorming group creativity technique
11	Benchmarking	Internal and external benchmarking & best practices
12	Bottleneck	Bottleneck Analysis
13	C&E	Cause–effect diagram
14	CBA	Cost-benefit analysis
15	Charter	Project charter
16	Charts	Process control charts
17	COPQ	Cost of poor quality
18	Cpk	Process capability analysis
19	CSA	Customer satisfaction analysis
20	CTQ	Critical to quality
21	CTT	Critical to time
22	DMAIC	Define-Measure-Analyze-Improve-Control cycle
23	DMADV	Define-Measure-Analyze-Design-Validate
24	DPMO	Defects per million opportunities
25	DOE	Design of experiments
26	Fishbone	Fishbone Diagram
27	FMEA	Failure mode effect analysis
28	Gage R&R	Gage Repeatability and Reproducibility
29	Gantt	Gantt Chart
30	Gemba	Go and see for yourself
31	Heijunka	Leveling of work flow
32	JIDOCA	Automatic Detection
33	JIT	Just in time
34	Kaizen	Kaizen events
35	Kanban	Kanban board
36	KANO	KANO model
37	KPIs	Key performance indicators dashboard
38	Mapping	Process mapping (flow chart, SIPOC, Spaghetti diagram, etc.)
39	Network	Network diagram
40	OEE	Overall Equipment Effectiveness
41	Pareto	Pareto chart
42	PCE	process cycle efficiency
43	PDCA	Problem solving cycle (Plan-Do-Check-Act)
44	Poka-Yoke	Mistake Proofing
45	QFD	Quality function deployment
46	RACI	Responsible, Accountable, Consulted, Informed
47	RCA	Root cause analysis
48	SIPOC	Suppliers, Inputs, Process, Outputs, and Customers
49	SMART	SMART goals
50	SMED	Single-minute exchange of die
51	SW	Standard work
52	Taguchi	Taguchi method
53	Takt	Takt Time
54	TQM	Total quality management culture
55	TPM	Total productive maintenance
56	VAA	Value-added analysis
57	VOB	Voice of business
58	VOC	Voice of customer
59	VOP	Voice of process
60	δL	Sigma level

TABLE 2
PROPOSED LSS-TOOLS IN DMAIC METHODOLOGY

#	Most common LSS tools	Define	Measure	Analyze	Improve	Control
1	Brainstorming	x		x	x	
2	Project charter	x				
3	Critical To Quality (CTQ)	x			x	
4	Process mapping (SIPOC)	x			x	
5	Current performance (KPIs, OEE)		x	x		x
6	Sigma level and process capability		x			x
7	Check Sheet and histogram		x	x		
8	Value Stream Mapping (VSM)		x		x	x
9	Design of experiments (DOE, Taguchi)		x			
10	Lean wastes and non-value added		x			x
11	Takt time		x		x	
12	Pareto Diagram			x		
13	Scatter Diagram			x	x	
14	Process Control Charts			x		x
15	ANOVA and Hypothesis testing			x		
16	Cause & Effect Diagram			x		
17	Visual control (5S)				x	
18	Standard work (SW)				x	
19	Kaizen events				x	
20	Control plan					x
21	Process control charts					x
22	Standard operating procedures (SOP)					x
23	KPIs dashboard					x
24	Before / after analysis					x
25	Internal and external auditing					x
26	Lessons learned					x

II. LITERATURE REVIEW

There are a number of ways that companies have used LSS methodology to improve the performance, the most important of which are: [1], [2], [4], [5], [6], [7], [8]:

- Decreasing 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.
- Increasing process flexibility process performance requires rapid response to changes in supply and demand through the ups and downs of business cycles, as well as during crises. Companies with the most flexible supply chains are those that are specifically designed to meet the needs of the customer. Identifying Customer Critical Quality (CTQ) helps companies build customer focus and thus resilience into their supply chains.
- Reducing process 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.
- Reducing process costs: By eliminating inefficiencies and minimizing waste, LSS helps cut operational costs significantly, leading to improved profitability.
- Effective Problem Solving: LSS equips process with tools to identify root causes of issues and implement lasting solutions, ensuring continuous improvement.
- Creating a competitive advantage Based on the above benefits, applying LSS principles can create competitive advantage, improve employee morale and increase revenues and profits.

Based on the literature review, it was found that the most important critical success factors for LSS are as shown in Table (3)., [1], [2], [9], [10], [11], [12], [13].

TABLE 3
LSS-SCM CRITICAL SUCCESS FACTORS (CSFS)

Perspective	Factors	[1]	[2]	[9]	[10]	[11]	[12]	[13]
1) Managerial factors	1) Management support, commitment and involvement	x	x	x	x	x	x	x
	2) Leadership development and awareness	x	x		x	x	x	
	3) Clear strategic plan, business plan, vision and mission			x		x	x	x
	4) Effective external and internal benchmarking of best practices		x					
	5) Clear goals, objectives, policies, and KPIs		x	x				
	6) Information quality and sharing			x				x
	7) Focus on competitive priorities			x				
	8) Effective teamwork management					x		
2) Customer factors	9) Customer engagement and satisfaction						x	
	10) Effective customer relationship management (CRM)						x	
4) HRM factors	11) Effective Organizational structure & responsibility matrix		x	x	x		x	x
	12) Employee training, education and awareness	x	x	x	x	x	x	x
	13) Employee attitude, skills and expertise					x	x	
	14) Effectives reward, recognition and motivation system		x			x	x	
5 IT factors	15) Effective information and communication technology	x	x	x	x	x	x	x
	16) IT Infrastructure						x	
	17) Effective LSS software						x	
6) Facility factors	18) Effective facility layout, configuration and planning		x					
	19) Effective project selection, planning and control system	x	x	x	x	x	x	x
	20) Effective facility resources and infrastructure				x		x	
7) Continuous	21) Understanding LSS methodology, techniques and tools	x	x				x	x
improvement factors	22) Standardization of procedures and information							x
	23) Linking LSS tools to business strategy							x
	24) Linking LSS tools to supply chain							x
	25) Employee engagement, empowerment and satisfaction	x	x			x		
	26) Project success stories, best practices and benchmarking					x		x
	27) Effective change management and Organizational culture	x	x	x	x	x	x	
8) Financial factors	28) Financial resource capabilities			x	x	x	x	x
	29) Economic benefits			x				

Several studies have focused on the applications of LSS in manufacturing domain. Table (4) 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 [36]) indicate that applying the LSS approach can improving quality, reducingprocess variation, eliminating waste, improving production rate, improving process productivity, reducing cycle time, reducing non-value-added time, reducing lead time, reducing production cost, reducing unit price, and increasing customer satisfaction.

TABLE 4
LSS STUDIES IN MANUFACTURING DOMAIN

#	Contribution	Application	Main objectives	Main LSS Tools
[2]	Developed a LSS framework for manufacturing	A case study in production of fasteners in Egypt	- Improving process OEE - Improving sigma level - Improving process capability	DMAIC, Mapping, VSM, 8Waste, Pareto, δL, Charts, Process capability, 5S, OEE, DOE, TAG, RCA, C&E
[14]	Discussed a six-sigma framework for manufacturing	A case study in a spare parts company in Turkey	- Improving process performance - Reducing lead time - Reducing production cost	DMAIC, Mapping, δL, R&R%, ANOVA, FMEA, RCA, C&E
[15]	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
[16]	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
[17]	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, Process capability, RCA, C&E
[18]	Discussed a lean framework for manufacturing	A case study in a labeling and packaging manufacturing in Bangladesh	- Reducing lead time - Improving Utilized equipment effectiveness - Reducing Customer complaint rate	DMAIC, Charter, Mapping, VSM, 5S, charts, RCA, C&E
[19]	Developed a LSS framework for manufacturing	A case study in a Textile Sector	- Improving process quality & productivity - Reducing lead time	DMAIC, Charter, Mapping, VSM, 5S, charts, Process capability, RCA, C&E
[20]	Discussed a six-sigma framework for manufacturing	A case study in a rubber weather strips company in Indian.	- Reducing rejection rate - Reducing production cost	DMAIC, CTQ, Mapping, Pareto, C&E, 5S, CBA.
[21]	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, RCA, C&E
[22]	Developed a LSS framework for manufacturing environment	A case study in a bias tyre manufacturing	- Reducing waste - Improving OEE	DMAIC, Mapping, OEE, charts, Pareto, RCA, C&E
[23]	Developed a LSS framework for manufacturing	A case study in milking processes	- Reducing defect % - Reducing cost	DMAIC, Mapping, VSM, RCA, C&E, PDCA,
[24]	Discussed a LSS framework for manufacturing	A case study in steel industry	- Reducing non-value-added time - Improving Process cycle efficiency - Reducing lead time	DMAIC, Mapping, Charter, VSM, Pareto, RCA, C&E,

TABLE 4
CONT...

#	Contribution	Application	Main objectives	Main LSS Tools
[25]	Proposed a LSS - Quick Changeover - framework for manufacturing	A case study in ready-made garments (RMG) industry in Bangladesh	- Improving Process cycle efficiency - Reducing production cost	Mapping, SMED, RCA, C&E
[26]	Developed a LSS framework for manufacturing	A case study in a compound animal feed manufacturing in Ireland	- Reducing inventory stock - Reducing lead time	DMAIC, Mapping, VSM, Pareto, SW, PCC
[27]	Discussed a six-sigma framework for manufacturing	A case study in a packaging olives production	- Minimizing Process defects & variance - Reducing production cost	DMAIC, charter, Mapping, CTQ, Benchmarking, Pareto, DOE, Process capability, Charts, RCA, C&E
[28]	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
[29]	Proposed a LSS framework for manufacturing	A case study in an automobile manufacturing in Indian	- Reducing defect % - Increasing production rate - Reducing idle time	DMAIC, Mapping, Charter, VSM, 8Waste, Pareto, C&E, δL
[30]	Developed a LSS framework for manufacturing	A case study in an engine cylinder company in Indian	- Reducing defect % - Increasing sigma level.	DMAIC, Charter, Mapping, ABC, Pareto, Charts, C&E
[31]	Presented a LSS framework for manufacturing	A case study in laminated panel production	- Reducing machine downtime - Improving process OEE	DMAIC, Charter, Mapping, CTQ, Takt, VSM, OEE, Charts, C&E, PDCA, FMEA.
[32]	Developed a LSS framework for manufacturing	A case study in iron industry	- Reducing lead time - Reducing defect % - Increasing sigma level.	DMAIC, Charter, Gantt, Mapping, VSM, δL, Charts, 5Why, C&E
[33]	Proposed a six-sigma framework for manufacturing	A case study in a chemical company	- Reducing customer complaints	DMAIC, Charter, Mapping, Cpk, 5Why, C&E
[34]	Presented a VSM framework for manufacturing	A case study in footwear manufacturing	- Reducing defect % - Reducing lead time - Reducing WIP	DMAIC, VSM, Takt, DOE, Taguchi
[35]	Developed a LSS framework for manufacturing	A case study in food industry	- Improving process OEE	DMAIC, Mapping, VSM, OEE, ANOVA, 5S, C&E
[36]	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

III. PROPOSED LSS FRAMEWORK

Based on the analysis of the literature review, Table (5) shows the most common LSS objectives in manufacturing domain and the appropriate LSS tools to achieve these objectives. Table (6) shows the process lean (DWONTIME) waste analysis and appropriate LSS tools to overcome this waste. Table (7) shows the main resources, main objectives, main problems, and appropriate LSS tools to improve resource productivity. As shown in Table (8), LSS-DMAIC framework is developed to improve manufacturing efficiency and effectiveness.

TABLE 5
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 6
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	To wait unnecessarily, 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 7
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.

TABLE 8
PROPOSED LSS-DMAIC FRAMEWORK FOR MANUFACTURING PROCESSES

Phase	Objectives	Key Activities	Used Tools
Define	Studying process, product and problems in detail.	1) Defining the goals, objectives and scope of work	Brainstorming
		2) Building teamwork & developing project charter	Brainstorming
		3) Defining product description and required processes	Brainstorming
		4) Defining current situation (strength & weakness)	SWOT matrix
		5) Defining process problems and targets	Brainstorming
		6) Create a project charter & a project plan	Project charter
		7) Defining customer requirements & CTQ factors	CTQ and VOC
		8) Defining process mapping (flow chart, SIPOC)	SIPOC diagram
		9) Identifying key metrics	KPIs metrics
Measure	Designing and collecting the required information.	10) Designing standard templates & collect information	Brainstorming
		11) Measuring current performance evaluation	KPIs dashboard
		12) Measuring sigma level & process capability	Sigma level, Cpk
		13) Preparing current value stream mapping	VSM
		14) Measuring process wastes & defects	8 Lean wastes
Analyze	Applying analysis tools and identifying root causes	15) Using appropriate statistical analysis tools	7QC tools
		16) Analyzing process defects	Pareto chart
		17) Analyzing process variance	ANOVA
		18) Analyzing critical to quality (CTQ)	SPC & 7QC
		19) Analyzing process wastes & bottleneck	RCA
		20) Analyzing process parameters	DOE
		21) Conducting RCA and fishbone diagrams	C&E diagram
		22) Determining improvement recommendations	Brainstorming
Improve	Implementing solutions according to priorities	23) Identifying and prioritizing opportunities for improvement	Brainstorming
		24) Preparing the improvement plan	Brainstorming
		25) Training the teamwork groups	Advanced training program
		26) Implementing kaizen & lean principles	Kaizen, 5S, SW, … etc.
		27) Implementing six sigma principles	7QC tools
		28) Implementing changes and monitoring progress	Brainstorming
Control	Monitoring the process and achieving daily improvements	29) Developing and implementing a control plan	Brainstorming
		30) Designing and document standard practices	QA/QC
		31) Following process control charts	Control charts
		32) Following QA/QC checklists	QA/QC
		33) Following Kaizen improvement	Kaizen, 5S, SW, … etc.
		34) Following KPIs, Sigma level, process capability, …	KPIs dashboard
		35) Before / after analysis	KPIs analysis
		36) Creating a culture of continuous improvement	Kaizen events
		37) Documenting and standardizing processes:	Auditing
		38) Providing training and support	Brainstorming
		39) Preparing project close-out report	Brainstorming
		40) Communicating results & learned lessons	Brainstorming

IV. CONCLUSION

LSS has proven to be an effective methodology and strategy for the manufacturing sector's success to improve process productivity and quality. This study explored the state of the art, current trends, and perspectives of LSS in the context of the manufacturing sector. The results found that applying 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, and reduce unit price, and increase customer satisfaction. Furthermore, the results can be used for a systematic literature review by researchers and manufacturing leaders before embarking on a continuous improvement journey. Finally, this study proposed LSS-DMAIC framework to improve manufacturing efficiency and effectiveness.

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