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A Systematic Review of Lean Six Sigma in Manufacturing Domain

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Abstract: Manufacturing companies seek to improve competitiveness through continuous improvement in process productivity and product quality using Lean Six Sigma (LSS) methodology, which 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. This systematic review aims to explore the most popular topics within LSS in manufacturing over the past ten years (2014 to 2023), and to identify and analyze any gaps. Results found that LSS helps in improving quality, increasing sigma level, reducing non-added value, increasing productivity, reducing production costs, and improving customer satisfaction. Furthermore, the results can be used for a systematic literature review by researchers and manufacturing leaders before embarking on a journey of continuous improvement. Finally, this study proposed a LSS framework for the manufacturing domain, which includes 40 steps. Various tools like process mapping, KPIs, OEE, sigma level, seven quality control tools, process time analysis, value stream mapping, kaizen, 5S, brainstorming, and standard work have been used at different phases of DMAIC.

Keywords: LSS, DMAIC, Continuous Improvement, Quality, Productivity.

1. INTRODUCTION

Six Sigma was implemented by Motorola in the United States in the mid-1980s, Lean was developed by Toyota in Japan in the late 1980s, and the integration of Lean and Six Sigma principles began in the late 1990s. Lean Six Sigma (LSS) approach is a continuous improvement methodology formulated to increase customer satisfaction, improve process productivity, increase product quality, and reduce production costs, [3], [38], and [42]. As shown in Fig. (1), the core objective of LSS is to improve quality, cost, and accountability. International-Standards-Organization (ISO) has published three standards for LSS implementations, namely (ISO 18404:2015) as a standard for quantitative methods in LSS, [30], LSS methodology (ISO 13053-1:2011), [28] and LSS tools and techniques (ISO 13053-2:2011), [29].

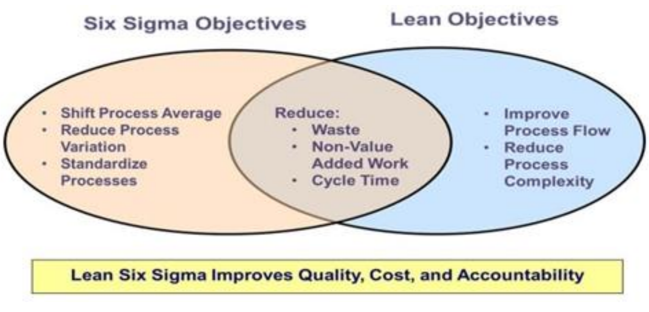

Fig1. Core objectives of Lean Six Sigma.

2. METHODOLOGY:

This study aims to provide a systematic literature review of all LSS papers that were in specialized journals from 2014 to 2023, to explore the most popular topics published in the field of LSS and to explore the gaps in each topic in the manufacturing discipline. Research strings were used such as: (lean), (six sigma), (lean six sigma), (lean sigma), (total quality management), (continuous improvement), (manufacturing), (production), and (case study). While the literature search was limited to the English language only. Table (1) shows the survey of LSS papers in manufacturing during the past ten years (2014 to 2023).

TABLE 1. Survey of LSS papers in manufacturing, over the past ten years (2014 to 2023).

#	Journal name	Number of papers	References
1	Int. J. of Lean Six Sigma	20	[1], [2], [6], [11], [15], [23], [33], [40], [42], [43], [45], [47], [49], [51],
2	Production Planning and Control	6	[10], [32], [35], [69], [71], [73]
3	Int. J. of Quality & Reliability Management,	5	[4], [5], [9], [55], [63]
4	Total Quality Management & Business Excellence	5	[12], [38], [50], [66], [68]
5	Quality Management Journal (ASQ)	3	[22], [36], [60]
6	Int. Conf. on Industrial Eng. and Operations Manag.	3	[14], [31], [41]
7	Quality Engineering (ASQ)	2	[7], [8]
8	Int. J. of Productivity & Performance Management	2	[54], [61]
9	Business Process Manag. J.	2	[3], [52]
10	Int. J. of Scientific & Engineering Research,	2	[20], [21]
11	Quality Innovation Prosperity	1	[48]
12	Int. J. Prod. Manag. Eng.	1	[65]
13	Production & Manufacturing Research	1	[24]
14	Quality and Reliability Eng. Int.	1	[17]
15	Industrial Engineering Journal	1	[59]
16	Int. J. Manag. Sci. Eng. Manag.	1	[13]
17	Int. J. of Scientific & Engineering Research	1	[18]
18	TQM J.	1	[37]
19	Eng. Research Journal (ERJ)	1	[19]
20	Int. J. of Supply Chain Manag.	1	[53]

3. LITERATURE REVIEW:

Several research papers focusing on critical success factors for LSS have been reviewed. For example; Youssouf, (2014), [74] developed a LSS framework to improve the quality of maintenance operations using several tools such as root cause failure analysis (RCFA), failure mode effect analysis (FMEA), design of experiments (DOE), pareto chart, leveling of work flow (Hishikawa), and visual control (5S). Indrawati, (2015), [25] proposed a LSS framework to improve sigma level and reduce non value added in an iron ores industry. Ben Ruben, (2017), [10] conducted a LSS framework with environmental considerations to improve sigma level and reduce overall environmental impacts in the automotive industry. Alkunsol, (2018), [6] adopted a LSS framework in a pharmaceutical industry to reduce the process wastes and defects. Hill, (2018), [24] mentioned a LSS framework for maintenance operations to improve effectiveness and suitability. Sodhi, (2019), [59] developed a LSS framework for waste management in a foundry unit to reduce scrap rate and reworking. Silva, (2019), [56] showed a LSS framework for manufacturing to improve process productivity and quality and reduce direct workforce. Pereira, (2019), [48] explained a LSS framework in the mold industry for improving quality and productivity. Nandakumar, (2020), [44] studied the bottleneck identification and process improvement by applying LSS techniques. The proposed method helped in improving overall equipment efficiency, improving productivity and reducing production fluctuations. Sharma, (2022), [54] proposed a LSS framework in an automobile light industry to reduce defect ratio and increase sigma level.

4. RESULT & DISCUSSION:

To achieve the overall targets of this work, the literature was systematically reviewed. Table (2) presents the survey of LSS objectives in manufacturing domain over the past ten years (2014 to 2023). As shown in Fig. (2), the top five of LSS objectives in manufacturing domain are as follows: (1) Reducing defect ratio and Improving sigma level, (2) Reducing cycle time, (3) Improving production rate, (4) Reducing process wastes and non-value-added activities, and (5) Reducing production cost.

Table (3) shows the survey of LSS application in manufacturing domain over the past ten. According to Fig. (3), the top five of LSS applications in manufacturing domain are as follows: (1) Small & medium sized enterprises

(SMEs), (2) Food industry, (3) Maintenance operations, (4) Supply chain management, and (5) Automotive Industry.

Table (4) illustrates the survey of LSS tools in manufacturing domain over the past ten years. As shown in Fig. (4), the top five of LSS tools in manufacturing domain are as follows: (1) Process mapping and SIPOC, (2) Defect analysis and sigma level, (3) Value stream mapping (VSM), (4) Seven Quality Control tools (7QC), and (5) Lean wastes, Visual control (5S) and Standardized work (SW).

Based on this review, it was found that the most important success factors for LSS implementation are as follows, [1], [3], [4], [26], [36], [37], [38], [47], [49], [51], [72]:

1) Management commitment, support and involvement,
2) Leadership style and development,
3) Employee training and education,
4) Employee engagement, empowerment, and satisfaction,
5) Effective information and communication technology infrastructure,
6) Understanding LSS methodology, tools and techniques,
7) Focus on customer, relationship and satisfaction,
8) Effective project planning and control system,
9) Effective change management process,
10) Effective organizational structure and job integration approach.

TABLE 2. Survey of LSS objectives in manufacturing, over the past ten years (2014 to 2023).

#	Objectives	References; for example,	#
1	Reducing defect ratio	[2], [10], [21], [22], [25], [44], [46], [56], [54], [67]	10
2	Improving sigma level	[2],[10], [21], [22], [25], [44], [46], [56], [54], [67]	10
3	Improving production rate	[2], [10], [17], [21], [41]	5
4	Reducing non-value-added	[6], [21], [22], [24], [25], [31], [59]	7
5	Reducing rework time	[10], [59]	2
6	Reducing cycle time	[3], [10], [21], [41], [44], [45], [46], [54], [56], [67]	10
7	Improving labor productivity	[2], [56]	2
8	Improving material productivity	[10]	1
9	Improving machine productivity	[3], [6]	2
10	Improving machine availability	[13], [24], [40], [74]	4
11	Improving energy productivity	[10]	1
12	Improving overall effectiveness	[41], [43], [44]	3
13	Reducing work in process (WIP)	[10]	1
14	Improving time utilization	[7], [21], [54].	3
15	Improving customer satisfaction	[3], [19], [40], [56]	4
16	Reducing lead time	[10], [21], [41] [46], [57]	5
17	Improving effectiveness	[7]	1
18	Reducing inventory cost	[3], [26], [54].	3
19	Reducing energy cost	[10]	1
19	Reducing production cost	[3], [10], [13], [21], [26], [40]	6
20	Improving profit ratio	[3], [26]	2

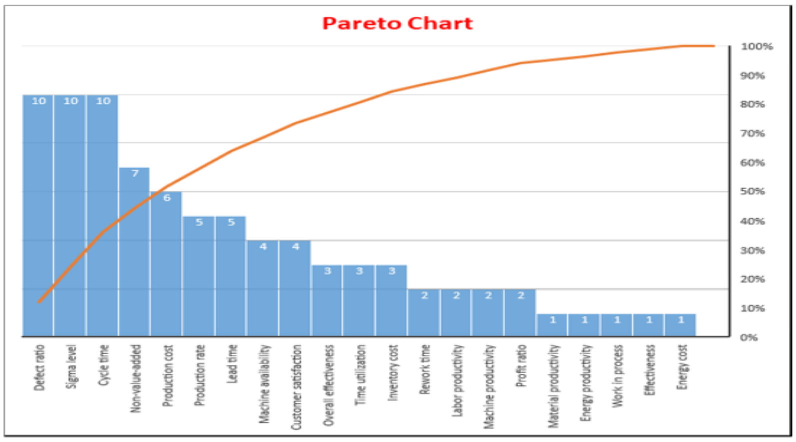

Fig 2. Pareto chart for LSS objectives in manufacturing.

TABLE 3. Survey of LSS application in manufacturing over the past ten years (2014 to 2023).

#	Application	References; for example,	#
1	Automotive industry	[10], [64]	2
2	Food industry	[11], [17], [39], [44], [67]	5
3	Printing industry	[31], [14]	2
4	Textile industry	[2], [46]	2
5	Iron ores industry	[25]	1
6	Mold industry	[48]	1
7	Furnace nozzle industry	[62]	1
8	Cement bags industry	[21]	1
9	Forged industry	[56]	1
10	Bolts industry	[13]	1
11	Rotary switches industry	[69]	1
12	Sugar mill industry	[58]	1
13	Biopharmaceutical industry	[27]	1
14	Baggage handling industry	[7]	1
15	Pharmaceutical industry	[6]	1
16	Oil & gas industry	[45]	1
17	Wood furniture industry	[22]	1
18	Product development	[35]	1
19	Maintenance operations	[24], [33], [43], [74]	4
20	Supply chain & Logistica	[18], [19], [23], [53]	3
21	Small & medium sized enterprises (SMEs)	[14], [17], [21], [22], [31], [37], [40], [43], [46], [54] [56], [57], [59], [61], [66], [73]	16

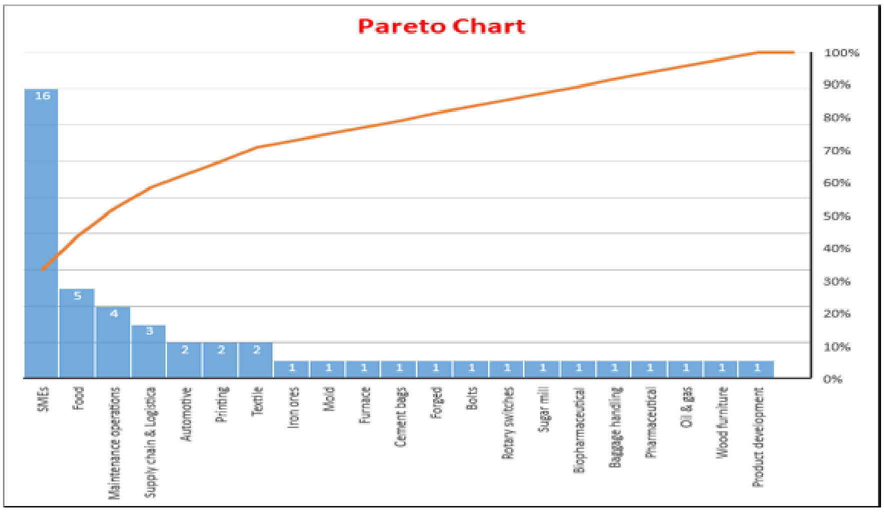

Fig 3. Pareto chart for LSS application in manufacturing

TABLE 4: Survey of LSS tools in manufacturing domain over the past ten years (2014 to 2023).

#	LSS Tools	References; for example,	#
1	Brainstorming	[10], [12], [48]	3
2	Project charter	[10], [12], [48]	3
3	CTQ, VOC, VOB	[10], [12], [56]	3
4	Defect analysis & sigma level	[10],[21],[22],[25],[44],[46],[54],[56],[67]	9

5	Process capability analysis	[10], [21], [46], [48]	4
6	Process mapping, SIPOC, Spaghetti	[10],[12],[8],[21],[43],[46],[48],[44],[67],[74]	10
7	Seven quality control tools	[11], [22], [24], [44], [45], [46], [67]	7
8	Cause & effect diagram	[3],[8],[10],[12],[21],[22],[24],[31],[44],[46],[48],[74]	12
9	Pareto diagram	[8], [10], [12], [22], [24], [31], [46], [48]	8
10	Value stream mapping (VSM)	[10], [21], [24], [31], [44], [45], [48], [56], [67]	9
11	KPIs, benchmarking	[10], [48], [56]	3
12	Design of experiments (DOE)	[10], [11], [22], [33], [44], [45]	6
13	ANOVA and hypothesis testing	[11], [44] , [45]	3
14	Lean wastes and non-value added	[21], [22], [25], [46], [48]	5
15	5S, Standard work, Poka-Yoke	[10], [44], [48], [56], [67]	5
16	Kaizen events	[48]	1
17	Go and see for yourself (Gemba)	[48]	1
18	Failure mode effect analysis (FMEA)	[8], [24], [25], [43], [48], [74]	6
19	Quality function deployment (QFD)	[10], [12], [56].	3
20	TPM and OEE	[43], [45]	2
21	Control plan	[39], [56]	2
22	Takt time	[56]	1
23	Kanban system	[21]	1
24	Pull system & Cellular manufacturing	[3]	1
25	Heijunka (leveling of work flow)	[21]	1
26	Andon, (a visual control device)	[39]	1
27	Continuous flow manufacturing (CFM)	[56]	1
28	Just in time (JIT)	[56]	1
29	Single-minute exchange of die (SMED)	[56]	1
30	Network and Gantt chart	[12]	1
31	Cost of poor quality (COPQ)	[10]	1

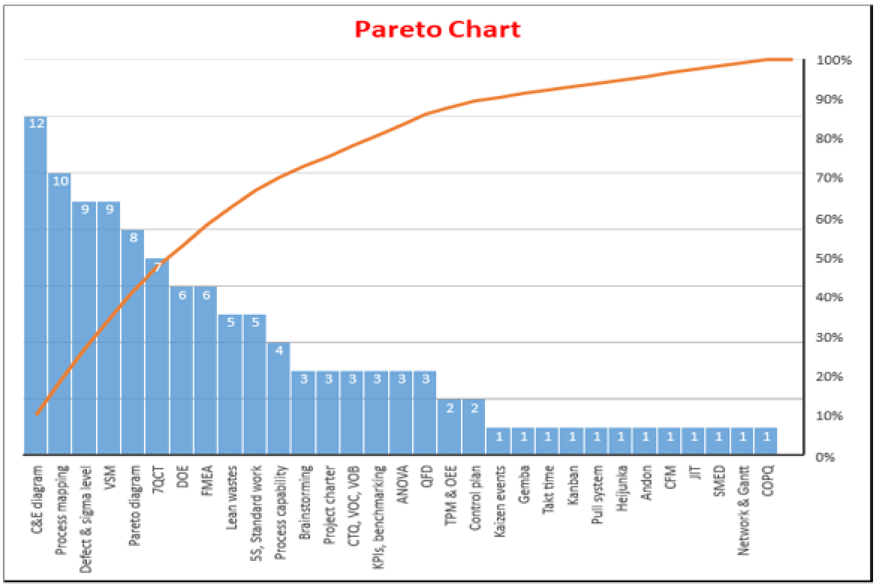

Fig 4. Pareto chart for LSS tools and techniques.

TABLE 5: Use of main LSS tools in different steps of DMAIC methodology.

#	Main Tools	Define	Measure	Analyze	Improve	Control
1	Brainstorming	x		x	x	
2	Project charter	x				
3	CTQ, VOC, and VOB	x			x	
4	Process mapping, SIPOC, and spaghetti	x			x	
5	Quality function deployment (QFD)	x			x	
6	Current performance (KPIs & OEE)		x	x		x
7	Sigma level and process capability		x			x
8	Check Sheet and histogram		x	x		
9	Value Stream Mapping (VSM)		x		x	x
10	Design of experiments (DOE) & Taguchi method		x			
11	Lean wastes and non-value added		x			x
12	Takt time		x		x	
13	Pareto Diagram			x		
14	Scatter Diagram			x	x	
15	Process Control Charts			x		x
16	ANOVA and Hypothesis testing			x		
17	Cause & Effect Diagram			x		
18	Network and Gantt chart				x	
19	5S, SW, Poka-Yoke, and Jidoka				x	x
20	Kaizen events				x	x
21	Go and see for yourself (Gemba)				x	x
22	RCA, FMEA, and RCFA				x	
23	Total productive maintenance (TPM)				x	
24	Kanban system				x	
25	Andon, (a visual control device)				x	
26	Heijunka (leveling of work flow)				x	
27	Just in time (JIT)				x	
28	Single-minute exchange of die (SMED)				x	
29	Control plan					x
30	Process control charts					x
31	Standard operating procedures (SOP)					x
32	KPIs dashboard					x
33	Before / after analysis					x
34	Internal and external auditing					x
35	Lessons learned					x

TABLE 6. Proposed LSS - DMAIC framework.

Phase	Objectives	Key Activities	Used Tools
Define	Study process, product and problems in detail.	1) Define teamwork and responsibilities matrix	Brainstorming
		2) Define company problems, and top priorities	Brainstorming
		3) Define product description, CTQ and VOC	CTQ and VOC
		4) Define process mapping and SIPOC	SIPOC
		5) Define problems, objectives, and targets	Brainstorming
		6) Design standard templates	Brainstorming

Measure	Design and collect the required information.	7) Measure current performance evaluation	KPIs
		8) Measure overall equipment effectiveness	OEE
		9) Construct current value stream mapping	VSM
		10) Measure process defect frequency	Check sheet
		11) Measure sigma level and process capability	Sigma level, Cpk
		12) Measure process output samples	DOE
		13) Measure key process output variable	CTQ
		14) Measure process wastes	8 Lean wastes
Analyze	Apply analysis tools and identify root causes	15) Analysis current performance evaluation	KPIs
		16) Analyze overall equipment effectiveness	OEE
		17) Analyze process defects	Pareto chart
		18) Analyze process variance	ANOVA
		19) Analyze process output samples	SPC & 7QC
		20) Analyze process wastes	8 Lean wastes
		21) Identify Root causes	C&E diagram
		22) Determine improvement recommendations	Brainstorming
Improve	Implement solutions according to priorities	23) Prioritize the solutions	Brainstorming
		24) Prepare the improvement plan	Brainstorming
		25) Prepare action plans	Brainstorming
		26) Plan for kaizen activities	5S, SW
		27) Train the process teamwork	Training program
		28) Implement the improvements plans	Kaizen events
		29) Evaluate the results	CBA
Control	Monitor the process and achieve daily improvements	30) Design and document standard practices	QA/QC
		31) Follow daily process control plan	Checklist
		32) Follow process control charts	Control charts
		33) Follow QA/QC checklists	QA/QC
		34) Follow daily kaizen improvements	5S, SW
		35) Follow daily 8 lean wastes	8 Lean wastes
		36) Design target value stream mapping	VSM
		37) Design performance evaluation and KPIs	KPIs, OEE
		38) Calculate performance evaluation and KPIs	KPIs, OEE
		39) Calculate sigma level and process capability	Sigma level, Cpk
		40) Identify opportunities for future improvements	Kaizen events

5. PROPOSED LSS FRAMEWORK:

So that the results of this research can be used by researchers and manufacturing leaders before embarking on an LSS journey, a LSS framework for the manufacturing domain has been proposed. Table (5) shows the use of main LSS tools in different steps of DMAIC methodology. Table (6) presents the proposed LSS-DMAIC framework for the manufacturing domain, which includes 40 steps. Various tools like KPIs, OEE, sigma level, seven quality control tools, process time analysis, value stream mapping, kaizen, 5S, brainstorming, and standard work have been used at different phases of DMAIC

6. CONCLUSION:

LSS has proven to be an effective methodology and strategy for the success of the manufacturing sector for improving process productivity and quality. This study examined the LSS techniques and applications most commonly used in manufacturing case studies over the past ten years (2014 to 2023). A literature review process indicated the effectiveness of LSS diffusion. The main results indicate that the application of the LSS approach can improve product quality, reduce process variance, eliminate process wastes, improve process productivity, improve production rate, reduce cycle time, reduce lead time, reduce production cost, and increase customer satisfaction. Finally, the present study proposed a LSS framework for manufacturing domain.

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