Lean six sigma for manufacturing industry: a review

Khawarita Siregar¹, Farida Ariani², Elisabeth Ginting¹, Trie Dinda M P¹

¹ Industrial Engineering Department, Universitas Sumatera Utara
² Mechanical Engineering Department, Universitas Sumatera Utara

Email: Khawaritasiregar@yahoo.com

Abstract. The literature review is a review of several published journals on a particular topic. Lean Six Sigma (LSS) is a method that has been widely used in research in various fields and continues to grow, so it is important to review this method to get the most common topics solved. LSS is an ongoing improvement methodology with the aim of reduce costs for producing poor quality, reduce waste of non-value-added activities and increase value for consumers and company. The purpose of this review is to find out the objective of using LSS, the tools used in implementing LSS in the manufacturing industry and to identify the factors that have caused the company's failure to implement LSS.

1. Introduction

Lean Six Sigma is the most popular method for continuous improvement in the manufacturing and service sectors. Lean is a continuous effort to eliminate waste and increase the value added products (goods / services) in order to provide more value to the customer [1]. The focus of Lean is to identify and eliminate non-value-added activities in design, production (for manufacturing) or operations (for services), and supply chain management that is directly related to customers. There are 8 types of waste namely production, transportation, delays, process, inventories, movement, defective products and defective design [2]. Six Sigma was formed at Motorola, which is a method of emphasizing variation [3].

Six Sigma is defined as a business strategy that increases and reduces the factors of defects and failures, increases productivity, reduces cycle time and productions costs. Six Sigma is a statistical method used for reducing variations in any process [4,5], reducing costs in manufacturing and services, make savings in the bottom line, increasing customer satisfaction [6,7,8,5], measuring defects, improving quality of product, and reducing defects to 3.4 parts per million of opportunities in the organization [9,10].

Lean Six Sigma is defined as a methodology and strategy business to improves process performance, customer satisfaction and outcomes. LSS is a strong strategy in process management with the aim to eliminate defects and reduce variations in product manufacturing service processes, which leads to excellence business process [11]. The LSS aims to improve capabilities of organization, reduce costs of production [10] and maximize value of stakeholder by improving quality [12]. In theoretical conceptual studies, LSS leads to a gradual increase in product quality level and process reliability and thus support the implementation of lean practices such as JIT, TPM and others [13]. In addition, LSS eliminates rework time, increases productivity, increases flexibility system and reduce inventory levels between workstations [14].
2. Research Methods
This paper discusses the most common topics resolved with the Lean Six Sigma (LSS) method in the manufacturing sector, and to identify the factors that led to the failure of the LSS strategy, by reviewing the literature that was previously published.

Journals for research articles are carried out through academic journals in the field of LSS which are published in leading database journals. A review must be made for articles showing the application of LSS in the manufacturing sector. LSS articles with applications in other sectors such as health care, services and construction are excluded. Research articles relating to LSS and implemented in the manufacturing sector are the research criteria. Based on the search, it was determined that the articles were reviewed starting from articles published since 2005.

After the journal was sorted, 21 journals were obtained from a total of 50 LSS journals in the manufacturing industry that fit the criteria. The journals we reviewed did not only come from one country but several countries such as the United States, Britain, India, Indonesia, China, Arabia, Taiwan. The selected journals will be read back to consider the implementation of LSS, and finally 19 journals were obtained with case studies.

3. Results
The most common topics in the manufacturing sector based on the collected journals.

3.1. Benefits of Successful LSS Implementation in the Manufacturing Sector
Based on 21 journals reviewed, there were 19 case study journals. Journals come from various countries, namely the United States, Britain, India, Indonesia, Arabia, Taiwan and China. The company benefited greatly from implementing LSS. According to the journal, 10 of the company's most common advantages are improving quality, reduced cycle time, reduced preparation, reducing waste, reducing production costs, increasing efficiency, increasing production and customer satisfaction, reducing shipping, increasing process capability and reducing machine damage time.

The success of LSS is not limited to one industry, but it covers many industries. Based on these reviews it can be seen that LSS has been successfully implemented in the automotive, cigarette manufacturing, military, aircraft manufacturing, paper and others industries.

Based on table 1 we can get tools the most common used in LSS applications. The tools most common are SIPOC diagram (10 cases), DOE (9 cases), VSM (9 cases), 5S (7 cases), FMEA (6 cases) and Capability Analysis (5 cases).

3.2. The motivations that LSS implements in the manufacturing industry
The goal of companies to implement LSS is to get better. There are many things that motivate companies to implement LSS in their companies such as to increase profit [18] [30], To reduce costs [18] [21] [27] [29] [30] [32], to reduce cycle times [18] [27], to improve the capability process manufacturing [19] [10] [36] [4], to reduce variation of process [20], to eliminate waste/ defect [20] [22] [26] [28] [30] [31], to achieve operational excellence [23], to improve the operation and performance [24] [34] [4], To improve the efficiency [25] [28] [31] [33], to improve the bottom line [26] [18], to improve quality [25] [28] [10] [33] [36] [4], to increase production capacity [27] [30], to support the workforce and inventory [27], to achieve a competitive advantage in quality and market share [30] [18], to increase customer satisfaction [21] [23] [24] [34] [11].
| Table 1. Successful Implementation of Lean Six Sigma in Manufacturing Sector |
|-------------------------------------------------|
| **Industrial** | **Countries** | **Objective of** |
| **Objective of** | **Objective of** | **Implementation** |
| **Implementation LSS** | **Implementation** | **Tools and Methods** |
| **Benefits** | **Benefits** | **Benefits** |
| 1 | Armament Products [18] | USA | a. To improve benefits | 5S, VSM, TPM, Process map, capability analysis, SPC, ANOVA, DOE, control charts, root cause analysis | a. 91% increase in quality, b. 70% cost reduction in cost, delivery 67% |
| 2 | Iron Ore [19] | Indonesia | a. To improve the capability of manufacturing process | FMEA, Process Mapping Capability analysis | - |
| 3 | Manufacturing Automotive Components [20] | India | a. To eliminate waste | DMAIC, SIPOC diagram, QFD, Pareto chart, VSM, 5 why analysis, cause and effect diagrams, brainstorming, 7s, SOP | a. Increase corporate sigma rate, b. Reduce defects internal to 6000 ppm from 16,000 ppm, c. Reduced environmental impact to 33 Pt from 42 Pt |
| 4 | Aircraft Manufacturing Company [21] | US | To improve the bottom line by reducing the cost | C & E analysis, Kanban, Jidoka | a. Reduction in inventory, waste, production cost, work time and cycle time, b. Improved quality, c. Increased production and customer satisfaction, Reduce damaged tires from 22-25% to 15% in one month total production |
| 5 | Tire Manufacturing Companies [22] | India | To reduce the defects of occurring in the production | VSM, 5S, Root-cause analysis | - |
| 6 | Auto Ancillary Conglomerate [23] | India | To achieve excellence operational | SIPOC, Pareto charts, CTQ analysis, Cause and effect diagram, Gemba, ANOVA, Capability analysis, root causes analysis | a. Savings significant financial, b. Reducing waste in processes and systems, c. Improve customer satisfaction |
| 7 | Iron ore pelletising [24] | Oman | To increase key of operation and performance | SIPOC, VOC & CTS diagrams, Capability analysis, VSM, Cause and effect diagrams | a. Saves costs in the range of $ 300,000 per year, b. Increased customer satisfaction |
| 8 | Manufacturing PCB [25] | China | a. To improve the efficiency of the shimming process, b. To improve product quality | 5S, Process Mapping, FMEA, TPM, C & E analysis, ANOVA | a. Increased utilization rate from 66.77 to 92.71% within 3 months, b. Increased throughput of 22,500 PCB per day, c. Significant decrease in fixture search time, average of 4.73 to 1.53 minutes, d. Decreased pin defects from 72 to 11.5% within 3 months, and up to 1.8% in 6 months, e. Development of plans for future maintenance and replacement of equipment. |
| Industry                      | Countries     | Objectives of Implementation LSS                                                                 | Tools and Method                      | Benefits                                                                 |
|-------------------------------|---------------|-------------------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| 9 Automotive [26]             | Iran          | a. To reduce defects<br>b. To improve results                                                 | SIPOC diagram, CTQ analysis, R & R Gauge, brainstorming, SOP, ANOVA               | a. Improve grinding process yield from 27% to 93.3%<br>b. Reduced disability costs (estimated $ 40,000) |
| 10 Ownership Military Products [27] | Worldwide | To increase production capacity, guarantee customer returns, support labor and inventory, reduce production costs, reduce cycle time. | SIPOC diagram, process mapping, brainstorming, C & E analysis, DOE, SPC         | a. Reduced total cost 50%, labor required 32%<br>b. Reduced cycle time 53%, return backlog 82%, inventory 50%<br>c. Increased production capacity 52%<br>d. Increased customer perception effect |
| 11 Cigarette Paper [28]      | Indonesia     | To continuously improve quality product by minimizing nonconformities, minimizing waste and improving overall efficiency of production process | DMAIC                                 | a. Increasing cycle efficiency 12.64%<br>b. Reducing production time by 165.92 minutes. |
| 12 Panel Equipment [29]       | Taiwan        | To demonstrate continuous improvement in forecasting manufacturing costs                      | DMAIC, SIPOC, ANOVA, FMEA, SSM, 5S diagram, Capability analysis                 | a. Reduced level Different costs<br>b. Eliminate variations<br>c. Cost savings of US $ 4,710,262<br>d. Improve process capability index of Cp and Cpk from 0.78 and 0.64 to 1.62 and 1.49 |
| 13 Touch Panel [11]           | Taiwan        | a. To reduce process capability<br>b. To improve quality                                      | DMAIC, Design of Experiments (DOE), SIPOC diagram, VOC, CTQ, affinity diagram, Kano model, brainstorming, fishbone diagram | a. Increase production<br>b. Hidden factors eliminated<br>c. Reduce touch panel quality defects |
| 14 Cleaning Equipment Manufacturing [30] | US            | a. To reduce costs, waste and protect revenue.<br>b. To achieve competitive advantage in quality and market share<br>c. To increase production capacity of | CTQ, brainstorming, SIPOC, VSM, Pareto analysis, root-cause analysis, FMEA, Kanban | a. Cost reduction per year ($ 660,000)<br>b. Reduction of work cell 50% |
| Industry | Countries | Objectives of Implementation LSS | Tools and Method | Benefits |
|----------|-----------|----------------------------------|------------------|----------|
| Gas Engineering and Organization [31] | USA | a. To improve the time of efficiency, standardization b. To remove products and other materials that are no longer used. | Spaghetti diagram, VSM, Poka-yoke, 5S | a. Reduce 1,163 annual working hours b. Increase productivity by 18-48% of variabroduction c. Reduce the cost10-35% d. Improve employee morale |
| Biopharmaceutical [32] | Arab | To reduce product cost | DMAIC, Process mapping, SIPOC diagram, VSM, CTQ, cause and effect matrix, FMEA | a. Reduced process cycle time from 1.310 to 592.5 minutes b. Reduced manufacturing cost (cost MYR 141,480 per year) c. Increased productivity and flexibility |
| Airfoil Compressor Factory [33] | AS | To improve product quality and efficiency | C & E analysis, FMEA | a. Increase sigma value from 0.868 to 3,207 b. Create an effective storage system c. Eliminate unnecessary tools d. Increased process efficiency significantly e. Reduced defective product |
| Rotary Switches [34] | India | To improve timing performance | VSM, Pareto chart, cause and effect analysis, DMAIC approach, control charts, DOEs, 5s, kanban, TPM, FTA | a. Reduction of defective products by about 10% b. Reduced lead time 180 s /engine c. FTY increased to 95% d. Capability Process increased to 1,5 e. Increase customer satisfaction f. Disability Per Unit (DPU) reduced to 0.0275 |
| Spocket Gear [35] | Indonesia | To improve product quality and reduce lead time | SPOC diagram, VSM, VOC, MEWMA control chart, five why, fishbone diagram, 5s and SOP | a. Reducing lead time from 221,381 to 217,740 minutes b. Increased quality up to 90% c. Increased cycle efficiency from 94.38% to 95.96% |
3.3. Factors of LSS implementation failure in the manufacturing industry

Some authors argue that some companies have successfully deployed continuous improvements significant such as Lean and Six Sigma, but some companies fail to benefit from implementing their LSS and others fail to achieve the results [37]. The most common LSS critical failure factor in the manufacturing sector will be presented in Table 2.

| No | Factor                          | Reference                                                                 |
|----|---------------------------------|---------------------------------------------------------------------------|
| 1  | Lack of employee involvement    | Pepper and Spedding[38]; Jeyaraman and Kee Teo [39], Antony et al. [40],  |
|    |                                 | Arumugam et al. [41], Martinez-Jurado and Moyano-Fuentes [42], Nwabueze [43]. |
| 2  | Poor communication              | Pedersen and Huniche [44], Antony et al. [45], Bhasin [47], Scherrer-Rathje et al. [46], Chakravorty [4] |
| 3  | Lack of awareness of Lean Six Sigma | Louie and Anbari [48], Gurumurthy and Kodali [49], Martinez-Jurado and Moyano-Fuentes [42], Panizzolo et al. [50], Psychogios et al. [51] |
| 4  | Lack of top management commitment | Bhasin's[47]; Burcher et al. [52] |
| 5  | High implementation costs       | Bhasin [47], Panizzolo et al. [50] Percin and Kahraman [53] |
| 6  | Not wanting to change           | Bhasin [47], Burcher et al. [52] |

4. Conclusion

Based on the authors' reviews, the use of LSS in manufacturing not only in certain regions but is widespread such as the United States, UK, India, China, Taiwan, Indonesia, etc. LSS is also used in almost all types of manufacturing industries such as shipping, automotive, paper, pharmaceuticals, iron, etc. There are many topics we found from journal reviews. The topics are:

1. Benefits of LSS: Improved quality, reduced cycle times, reduced inventory, reduced waste, reduced production costs, Increased cycle efficiency, Increased production and customer satisfaction, reduced shipments, Improved Capability Process, reduced in machine breakdown time
2. The common tools: SIPOC diagram (9 cases), DOE (9 cases), VSM (8 case), 5S (6 cases), FMEA (6 cases), Capability Analysis (5 cases)
3. The most common motivations are: to reduce costs, to eliminate waste / defective products, to improve quality, to improve customer satisfaction
4. Factors of failure: poor communication, lack of awareness about LSS, lack of employee involvement.

There are gaps found in LSS literature such as LSS standardization, use of key CI methodologies, LSS implementation in SMEs. This paper has limitations due to the number of journals reviewed, and research is only for the manufacturing sector only.

References
1. Vincent Gaspersz 2007 *Lean Six Sigma for Manufacturing and Service Industries* (Jakarta: PT Gramedia Pustaka Utama)
2. Wan HD, Frank Chen F 2008 *A leanness measure of manufacturing systems for quantifying impacts of lean initiatives* p 6567
3. Antony, J 2011 *Six sigma vs lean: some perspectives from leading academics and practitioners* (International Journal of Productivity and Performance Management) p 185.
4. Chakravorty et al 2012 *Lean Six Sigma (LSS): an implementation experience* (European Journal of Industrial Engineering) p 118.
5. Näslund D 2008 *Lean six sigma and lean sigma: fads or real process improvement methods* (Business Process Management Journal ) p 269
6. Drohomeretski E et al 2013 *Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy* (International Journal of Production Research) p 804-824.
7. Shah R, Chandrasekaran A and Linderman K 2008, *In pursuit of implementation patterns: the context of Lean and Six Sigma* (International Journal of Production Research) p 6679
8. Manville G, Greatbanks R et al 2012 *Critical success factors for Lean Six Sigma programming* (International Journal of Quality & Reliability Management) p 7.
9. Lee L and Wei C 2009, *Reducing mold changing time by implementing Lean Six Sigma* (Quality and Reliability Engineering International) p 387.
10. Chen M and Lyu J 2009 *A Lean Six-Sigma approach to touch panel quality improvement* (Production Planning & Control) p 445.
11. Snee RD 2010. *Lean Six Sigma - Getting Better All the Time* (International Journal of Lean Six Sigma) p 9.
12. Laureani A and J Antony 2012 *Critical Success Factors for the Effective Implementation of Lean Sigma* (International Journal of Lean Six Sigma) p 274.
13. Arnheiter ED and J Maleyeff 2005 *The Integration of Lean Management and Six Sigma* (The TQM Magazine) p 5.
14. Chen et al 2010 *From Value Stream Mapping to a Lean / Sigma Continuous Improvement Process: An Industrial Case Study* (International Journal of Production Research) p 1069.
15. Raval, SJ, and R Kant 2017 *Study on Lean Six Sigma Frameworks: A Critical Literature Review* (International Journal of Lean Six Sigma) p 275.
16. Laureani A and J Antony 2017 *Leadership Characteristics for Lean Six Sigma* (Total Quality Management & Business Excellence) p 405.
17. Okoli C and Schabram K 2010 *A guide to conducting a systematic literature review of information systems research* (Working Papers on Information Systems) p 26.
18. Corbett LM 2011 *Lean Six Sigma: the contribution to business excellence* (International Journal of Lean Six Sigma) p 118.
19. Indrawati Sri, Ridwansyah Muhammad 2015 *Manufacturing Continuous Improvement Using Lean Six Sigma: An Iron Ores Industry Case Application* (Procedia Manufacturing) p 528.
20. Ben Ruben et al 2017 *Implementation of Lean Six Sigma Framework with Environmental Considerations in an Indian Automotive Component Manufacturing Firm* (Production Planning & Control) p 1193.
21. Akbulut-Bailey AY et al 2012 *Lean Six Sigma at an aerospace company* (International Journal of Technology Management) p 18.
22. Bhuian N et al 2006 *A sustainable continuous improvement methodology at an aerospace company* (International Journal of Productivity and Performance Management) p 671.
23. Gijo, Raniprasad et al 2018 *Lean Six Sigma Approach in an Indian Auto Ancillary Conglomerate: A Case Study* (Production Planning & Control)
24. Garza-Reyes JA et al 2016 *A Lean Six Sigma Framework for the Reduction of Ship Loading Commercial Time in the Iron Ore Pelletising Industry* (Production Planning & Control) p 1092.
25. Lee L and Wei C 2009 *Reducing mold changing time by implementing Lean Six Sigma* (Quality and Reliability Engineering International) p 387.
26. Noori B and M Latifi 2018 *Development of Six Sigma Methodology to Improve Grinding Processes* (International Journal of Lean Six Sigma) p 50.
27. Pickrell G, Lyons J and Shaver J 2005 *Lean Six Sigma implementation case studies* (International Journal of Six Sigma and Competitive Advantages) p 369.
28. Syahputri K, Sari R M et al 2018 *IOP Conference Series: Materials Science and Engineering.*
29. Wang FK, Chen KS 2012 *Application of Lean Six Sigma to a panel equipment manufacturer* (Total Quality Management & Business Excellence) p 417.
30. Franchetti M and Yanik M 2011 Continuous improvement and value stream analysis through the Lean DMAIC Six Sigma approach: a manufacturing case study from Ohio (International Journal of Six Sigma and Competitive Advantage) p 278.
31. Waite PJ 2013 Save your steps (ASQ Six Sigma Forum Magazine) p 20.
32. Ismail A, et al 2014 Application of Lean Six Sigma Tools for Cycle Time Reduction in Manufacturing: Case Study in Biopharmaceutical Industry (Arab Journal Sciences English) p 1449.
33. Hardeman et al 2011 A case study: applying Lean Six Sigma concept to design more efficient airfoil extrusion shaping process (International Journal of Six Sigma and Competitive Advantage) p 173.
34. Ben Ruben, Vinodh S et al 2014 Implementing Lean Sigma in an Indian Rotary Switches Manufacturing Organization. (Production Planning & Control) p 288.
35. Surya and Khawarita Siregar 2013. Pengendalian Kualitas Dengan Menggunakan Diagram Kontrol MEWMA dan Pendekatan Lean Six Sigma Di PT. XYZ (e-journalTeknik Industri) pp 35-46.
36. Richard DS 2008 How lean is your Six Sigma program? (ASQ Six Sigma Forum Magazine) p 42.
37. Kumar M, J Antony, et al 2008 Common myths of Six Sigma demystified (International Journal of Quality & Reliability Management) p 878.
38. Pepper MPJ, Spedding TA 2010 The evolution of lean Six Sigma. (International Journal Quality Reliability Management) p 138.
39. Jeyaraman K, Kee Teo L 2010 A conceptual framework for critical success factors of lean Six Sigma: Implementation on the performance of the electronic manufacturing service industry (International Journal Lean Six Sigma) p 191.
40. Antony et al 2012 Lean Six Sigma for higher education institutions (HEIs): challenges, barriers, success factors, tools / techniques (International Journal of Productivity and Performance Management) p 940.
41. Arumugam V, Antony J et al 2013 Linking learning and knowledge to success in Six Sigma projects: an empirical investigation (International Journal of Production Economics) p 388.
42. Martínez-Jurado PJ and Moyano-Fuentes 2012 Key determinants of lean production adoption: evidence from the aerospace sector (Production Planning & Control: The Management of Operations) p 332.
43. Nwabueze 2012 Process improvement: the case of a drugs manufacturing company (Business Process Management Journal) p 576.
44. Pedersen ERG and Huniche M 2011 Determinants of lean success and failure in the Danish public sector: a negotiated order perspective, International Journal of Public Sector Management p 403.
45. J Antony, Kumar M and Madu CN 2005 Six sigma in small- and medium-sized UK manufacturing enterprises: some empirical observations (International Journal of Quality & Reliability Management) p 860.
46. Scherrer-Rathje, Boyle et al 2009 Lean, take two! Reflections from the second attempt at lean implementation (Business Horizons) p 79.
47. Bhasin S 2012 An appropriate change strategy for lean success (Management Decision) p 439.
48. Kwak YH and Anbari 2006 Benefits, obstacles, and future of six sigma approach Technovation) p 708.
49. Gurumurthy A and Kodali R 2011, Design of lean manufacturing systems using value stream mapping with simulation: a case study (Journal of Manufacturing Technology Management) p 444.
50. Panizzolo R et al 2012 Production Planning & Control: The Management of Operations p 769.
51. Psychogios et al 2012 Lean Six Sigma in a service context: a multi-factor application approach in the telecommunications industry (International Journal of Quality & Reliability Management) p 122.
52. Burcher et al 2010 Quality lives o: quality initiatives and practices in Australia and Britain (The TQM Journal) p 487.
53. Percin S and Kahraman C 2010 An integrated fuzzy multi-criteria decision-making approach for Six Sigma project (International Journal of Computational Intelligence Systems) p 610.