

Ranking the Important Failure Factors of Lean Six Sigma Deployment through Pareto Analysis

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Abstract

Lean Six Sigma has emerged as a business improvement strategy worldwide, emerged from the merger of Lean philosophy and Six Sigma methodology. The literature revealed many success stories of Lean Six Sigma deployment in diverse sectors but also indicated numerous failures at different stages of deployments. Therefore, this paper mainly focuses on exploring the failure factors of Lean Six Sigma deployment and examines the most influencing failure factors of Lean Six Sigma deployment. The study's outcome underlines the eight impactful failure factors of Lean Six Sigma deployment using the Pareto analysis of twenty-eight failure factors. The literature. The study revealed the impactful failure factors as lack of top management commitment and involvement, lack of synergy of LSS and business strategy, lack of awareness on LSS, resistance related to culture change, lack of availability of resources, and lack of training and education, lack of visionary leadership, and lack of financial resources. Understanding these failure factors of Lena Six Sigma deployment may help the professionals avoid failures.

Keywords

Lean Six Sigma (LSS), failure factor, barriers, improvement strategy, and Pareto analysis.

1. Introduction

The world has changed a lot due to technological disruptions, innovations, and interventions in activities in the manufacturing and service sectors in the last thirty years. The pace of change has even excelled drastically in the recent past, which led to numerous challenges and global competition to the business organization. Quality, price, productivity, timely delivery, after-sales services, robust design, etc., are crucial for business organizations in a highly competitive market. Therefore, business organizations are forced to enhance their products and processes by continuously adopting the latest business improvement strategies and bringing innovations. Some of such improvement strategies are Plan-Do-Check-Act (PDCA) cycle, Total Productive Maintenance (TPM), Lean Manufacturing, Six Sigma methodology, Total Quality Management (TQM), Agile Manufacturing, Integrated Management System (IMS), etc. Lean Six Sigma has unfolded as one of such improvement strategies in the last two decades.

According to a few research studies, Lean and Six Sigma grew independently during the previous century and emerged as quality improvement approaches (Albliwi et al. 2015; Alkunsol et al. 2019; Chakrabarty and Leyer 2013). Both the approaches, i.e., Lean and Six Sigma, have been adopted by various business organizations to improve products and processes with different tools and techniques (Walter and Paladini 2019). However, the Lean Six Sigma methodology employed the principles, tools and techniques of both approaches jointly to improve the quality, productivity, and customer satisfaction, maximizing the value to all the stakeholders (Laureani and Antony 2012). Recently conducted review studies concluded significant popularity of Lean Six Sigma methodology as a continuous improvement strategy based on significant growth in research articles published in peer-reviewed academic journals in the last decades (Panayiotou and Stergiou 2020; Patel and Patel 2021a; Raja Sreedharan and Raju 2016; Raval et al. 2018; Shokri 2017). In addition, Lean Six Sigma deployment in various sized business organizations, i.e., small, medium, and large-sized organizations, has increased various sectors like manufacturing, service, private, and public sectors (Laureani and Antony 2019). Implementing Lean Six Sigma in large-scale business organizations is reported better than in small and medium-scale business organizations (Kumar et al. 2011; Sambhe and Dalu 2011). Henceforth, it is essential to explore and understand the vital failure factors for Lean Six Sigma implementation through research.

1.1 Objectives

Looking at an introductory remark, the board objective of the present study is to develop learnings on failure factors of Lean Six Sigma deployment. The twin main objectives of the present study are as follows.

- ✓ The literature study identifies the failure factors of Lean Six Sigma deployment.
- ✓ To rank the vital failure factors using the Pareto analysis.

The next part of the research article is organized as follows. The second part covered the literature review on Lean Six Sigma methodology and failure factors of Lean Six Sigma deployment. The research methodology followed pursued during the study has been summarized in the third part. The fourth part presents with analysis of the failure factors of Lean Six Sigma implementation using Pareto analysis. The managerial implications of the findings are included in the fifth part. The conclusion is presented in the last part of the article.

2. Lean Six Sigma Methodology – A Literature Review

The literature review helps to understand the existing knowledge and explore the research field in a specific domain. Therefore, the literature on the Lean Six Sigma methodology has been carried out in two contexts. One of the contexts is to learn the historical progression of Lean Six Sigma, whereas the other is to examine the failure factors of Lean Six Sigma deployment.

Due to the repercussions and fallout of World War II, Japan suffered devastating damage to its infrastructure. Post-World War II, Japan lacked resources like a skilled workforce, economic constraints, policy deployment, and manufacturing (Holweg 2007). Toyota Motor Corporation was one such industry that was a subsidiary of Toyota Industries Corporation and diversified its business from automatic loom machinery manufacturing to automobile manufacturing during the same period. Based on the learnings from Ford's manufacturing facilities in the United States and the availability of different resources, Toyoda Eiji and Ohno Taiichi decided to develop their approach, known as the Toyota Production System (TPS). According to Ohno, one of the business goals was to eliminate waste (Ohno 1988). The focus of the TPS was to build quality products through waste elimination and to reduce the cost and delivery time (Danese et al. 2018). Until the 1970s oil crisis, the TPS received no global attention. Later, through a research project under the International Motor Vehicle Programme (IMVP), Massachusetts Institute of Technology (MIT) researchers studied the TPS, and the 'lean' was coined for the first time by John Krafcik (Krafcik 1988; Yamamoto et al. 2019). It was further popularized and recognized, as a philosophy, through a book titled "The Machine that Changed the World" by Womack and others (Womack et al. 1990). Henceforth, lean is a set of tools and techniques that eliminates waste, reduces delivery time, improves quality through value enhancement at a lower cost, and results in better customer satisfaction.

In the 1980s, Six Sigma began at Motorola, a US electronic product manufacturer, when Bill Smith reported non-detection of product defects during inspection & testing and a higher failure rate found during early use of products from such defective products. Bill Smith, Mikel Harry, and Bob Galvin devised a methodical, statistical-based technique, a four-phase methodology, i.e., measure, analyze, improve, and control (MAIC), with the primary goal of reducing product variation (Brue 2015; Harry 1998). Motorola reported the vast savings from the Six Sigma program compared to spending on Six Sigma. Motorola was honored with the first Malcolm Baldrige National Quality Award (MBNQA) in 1988 (Coronado and Antony 2002). In the Six Sigma program and as a metric, the Greek letter Sigma (σ) stands to highlight the variation in mean or variability. Six Sigma performance level equated to 3.4 defects per million opportunities (DPMO) with an assumption of the mean being shifted by plus or minus 1.5 sigma (Breyfogle 2003; Harry 1987; Zare Mehrjerdi 2011). The success of the Six Sigma methodology was achieved by Motorola, General Electric, Honeywell, and several other organizations that adopted the Six Sigma methodology in the 1990s to improve the performance of their products and quality. General Electric extended the four-phase methodology, adding define ('D'), making it to define, measure, analyze, improve, and control (DMAIC). Due to the wide adoption of the Six Sigma methodology by General Electric, General Electric achieved significant improvements in production with increased revenue (Eckes 2001; Hahn et al. 2000; Hoerl 2001). According to a few research publications, there are two approaches to the Six Sigma methodology: DMAIC and Design for Six Sigma (DFSS). As a problem-solving approach, the primary focus of DMAIC is to improve the existing processes, whereas DFSS focus on the development of new products and processes from the early part of the design (Antony et al. 2018; Edgeman and Dugan 2008; Snee 2010; Sreeram and Thondiyath 2015; Tjahjono et

al. 2010). Within twenty years from its inception, the Six Sigma methodology emerged as a business strategy to achieve breakthrough improvements from its original statistical consideration (Kwak and Anbari 2006).

Looking at the above, it is evident that Lean eliminates wasteful activities by reinventing the manufacturing processes, whereas Six Sigma reduces the variation in part and/or process independently (Lande et al. 2016; Park 2003). However, at the beginning of the 21st century, practitioners and researchers attempted a hybrid approach of Lean and Six Sigma to gain synergetic effects known as Lean Six Sigma. Literature reported that the first reference to Lean Six Sigma was revealed by Sheridan in 2000 (Sheridan 2000). According to George, “Lean Six Sigma, as a methodology, that maximizes shareholders value by achieving the fastest rate of improvement in customer satisfaction, cost, quality process speed, and invested capital” (George 2002). Since its inception, Lean Six Sigma has evolved as an approach to enhance product value and reduce variations by eliminating the non-value-adding activities from the manufacturing process (Singh and Rathi 2022). According to the literature, many organizations in the manufacturing and service sector have widely deployed Lean Six Sigma (Alhuraish et al. 2017). Few researchers reported that the Lean Six Sigma methodology's popularity had surged based on a significant rise in research publications in peer-reviewed journals in the past fifteen years (Gupta et al. 2020; Patel and Patel 2021a; Shokri 2017). Lean Six Sigma has been referred to differently by researchers, few of such as continuous improvement methodology (Null et al. 2019), process performance and improvement model (Wang et al. 2019), quality excellence methodology (Sunder M and Antony 2018), holistic strategy for business improvement (Albliwi et al. 2015), business improvement methodology (Laureani and Antony 2012), continuous improvement strategy (Patel and Patel 2021b) etc. However, few research studies reported that organizations had experienced hurdles in Lean Six Sigma deployment and discontinued deploying such improvement programs (Ashkenas 2012; McLean et al. 2017; Sony et al. 2019). Therefore, the present study attempts to rank the vital failure factor for Lean Six Sigma deployment using Pareto analysis based on secondary data.

3. Research Methodology

There are two objectives of the present study (i) to explore the literature to identify the failure factors for Lean Six Sigma implementation, and (ii) to rank the failure factors of Lean Six Sigma implementation using Pareto analysis. The research methodology followed during the present study incorporates three stages, i.e., planning, performing, and analysis & reporting (Tranfield et al. 2003). The objectives of the study and database selection to scrutinize the articles from the literature are incorporated in the planning stage. The Scopus database is considered for screening the articles as it is one of the largest electronic databases (Gupta et al. 2020). The article search was performed with keywords such as “Lean Six Sigma,” and “failure factors,” “barriers,” hurdles either in the title or the abstract of the article. The articles were published during the last fifteen years, i.e., from 2010 – 2021.

Further, the articles were screened during the performing stage based on the inclusion and exclusion criteria. As a part of inclusion criteria, the articles published in reputed journals, which follow the due process of peer-review, were considered with articles written in English as English is the most preferred medium of communication globally. As a part of the exclusion criteria, books, editorial notes, reports, preface, and conference papers were excluded from the study. A detailed investigation of shortlisted articles, based on the relevance to the objectives of the present study, was carried out during the analysis & reporting stage. Twenty-four articles were shortlisted for further analysis through the adopted research methodology. Figure 1 depicts the stage-wise research methodology followed during the present study.

4. Failure Factors of Lean Six Sigma Deployment – Data Collection and Analysis

According to Yadav et al., Lean Six Sigma deployment is initially resource-demanding and may result in considerable costs if not deployed effectively. These demands a thorough understanding of various aspects of Lean Six Sigma deployment, which focuses on failure factors of Lean Six Sigma deployments (Rathi et al. 2019; Yadav et al. 2018). The literature study revealed that the research articles analyzed the failure factors of Lean Six Sigma deployment focused on the automobile industry (Rathi et al. 2022), green lean six Sigma (Yadav et al. 2021), information technology (Shamsi and Alam 2018), environment (Ruben et al. 2018), and higher education (Antony et al. 2018). All the failure factors of Lean Six Sigma deployments were summarized from the shortlisted articles in Table 1. These failure factors were examined further with their relevance in Lean Six Sigma deployment and categorized for further analysis.

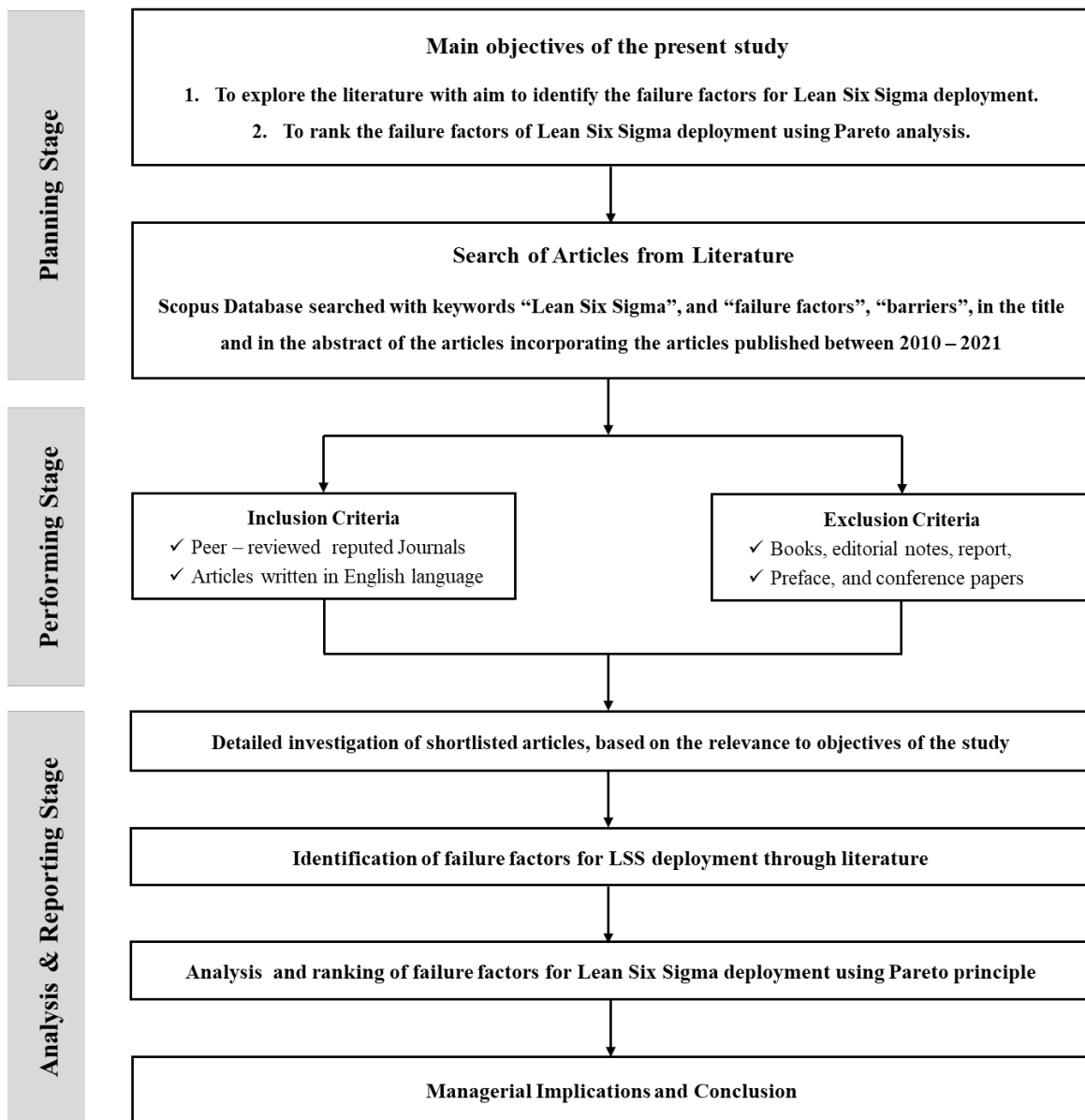


Figure 1: Research methodology of the present study

Table 1 Summarized failure factors of Lean Six Sigma deployment

Sr. no.	Failure Factors	Article Reference Number
1	Lack of determination, less authority to employees, insufficient supervision from line managers, defects and customer satisfaction cost and waste, scarcity of resources, absence of knowledge about LSS benefits and needs, absence of logistic support, wrong perceptions of LSS in terms of tools and techniques, difficulties in collection of data for LSS deployment, the mere experience of LSS implementation in company projects, lack of interaction between supplier and customers, improper data collection and retrieval system, ineffective material handling and transportation, problems faced in using effective techniques for LSS implementations, quality problems with supplied material, the disproportion between customer demands and company priorities	Rathi et al. 2019,

2	Management barriers, financial barriers, lack of education and training	Yadav et al. 2018
3	Deficiency of top management involvement, lack of resources, poor organizational capabilities, lack of leadership, lack of training and education, wrong perception of LSS as techniques, tools and practices, the resistance to culture change, poor project selection and prioritization	Singh et al. 2021a
4	Lack of awareness about LSS, lack of training and education, wrong LSS tool selections, lack of understanding of how to get started, lack of financial resources, lack of performance measurement system, lack of clear vision and future plan, poor top management commitment and involvement, poor strategic planning, poor estimation in LSS implementation cost	Singh et al. 2022
5	Performance belief, cultural fragmentation, resistance to change, lack of training, economic constraints, inefficient transportation organism, lack of standardized practices, dearth of progressive thinking, fear of failure, deficiency of knowledge based on different aspects of environments, obliviousness of reengineering, cost of poor quality, poor organizational culture, unawareness of various green lean six sigma strategies, improper project definition and analysis, wrong selection of Lean Green Six Sigma tools, lack of understanding of different types of VOC, lack of synergy between continuous improvement and strategic objectives of the organization, inappropriate Lean and Green areas identification, ineffective customer participation in Lean Green Sigma project, lack of management support and ineffectiveness, unclear organization vision and plans, deficiency of experienced GLS personnel	Kaswan and Rathi 2021
6	Lack of commitment and support from top management, resistance to change, inappropriate rewards and recognition systems, inconsistent monitoring and control, poor communication	Antony et al. 2020
7	Lack of management support, lack of awareness, lack of change management and resistance to change, lack of tools: unavailability of resources such as human, technical and financial, intangibility and unsustainability of the results, lack of communication, teamwork, project management	Alblooshi et al. 2020
8	Poor success rate, unrealistic expectations from LSS, unsustainable results, misuse of statistics, large tool set, unsupportive and uncommitted top management, lack of training and development, lack of synergy of LSS and business strategy, lack of link between LSS and customer needs, wrong project selection, premature discontinuation of LSS expert	Sony et al. 2019
9	Insufficient management commitment and involvement, lack of strategic thinking, lack of leadership, lack of resources, lack of training funds, unclear vision, wrong tool selection, poor alignment between company's goal and customer demand, poor selection of employees for belts training	Singh et al. 2019
10	Lack of top management commitment and involvement, lack of estimation of execution cost, lack of Lean/ Six Sigma expertise, unclear future plan and visions, in-effective roadmap for implementation, poor project selection and prioritization, resistance to culture change, poor organizational capabilities, insufficient organizational resources, weak infrastructure, misalignment between organizational goals, project aim and customer demand	Rathi et al. 2022
11	Management involvement towards LSS adoption, effective Six Sigma belt system, linking LSS to business strategy, effective utilization of financial resources, building trustworthy teamwork to execute LSS effectively, establishing LSS dashboard, create effective performance measurement system, define appropriate LSS toolset for each department, focused LSS training.	Yadav et al. 2017
12	Lack of clear vision and plans, ineffective training programs, imperfect knowledge of LSS tools and techniques, high implementation cost, lack of cross-functional teams, lack of understanding the statistical tool, no prior experience in LSS deployment	Sreedharan et al. 2018
13	Part-time involvement in LSS project, time-consuming, staff turnover in middle of the project, difficulty in data collection, difficulty in deciding about project scope	Shamsi et al. 2018
14	Lack of training and education, lack of top management commitment, lack of employee	Ruben et

	involvement, lack of resources, lack of leadership, improper communication, lack of awareness of LSS, resistance to change, improper selection of LSS tools, poor infrastructure,	all. 2018
15	Lack of top management commitment, lack of training and education, lack of funds for green projects, difficulty in adopting environmental strategies, stringent government policies, negative attitude towards sustainability concepts, improper communication, lack of defect monitoring analysis	Ruben et al. 2018b
16	Lack of management support and commitment, lack of communication, knowledge sharing, culture change, lack of education and training, recognition and reward systems	Mustapha et al. 2019
17	Strategic and visionary leadership, organizational culture resistance, poorly selected LSS projects, lack of communication,	Antony et al. 2018
18	Organizational culture, lack of commitment to start from the top management,	Yaduvanshi and Sharma 2017
19	Lack of top management attitude, commitment and involvement, lack of strategic planning, a weak link between the continuous improvement projects and the strategic objectives of the organization, lack of financial resources, lack of a performance measurement system, lack of estimation of LSS implementation cost, lack of clear vision and a future plan	Yadav and Desai 2017
20	Resistance to change, employees do not understand the implementation rationale, insufficient employee training, failure to empower people to drive implementation, lack of management support, and lack of resources.	Zhang et al. 2016.
21	Lack of expertise training program, lack of real support of management, fund constraints, poor quality of human resources, unsupportive culture and lack of motivation and encouragement, lack of KAIZEN environment	Kumar et al. 2016
22	Internal resistance, availability of resources, changing business focus and lack of leadership	Timans et al. 2012
23	Lack of awareness – yet another statistical tool, strong necessity of training, the resistance of employees (management change), high implementation cost, industry-specific issues	Psychogios et al. 2012
24	Lack of visionary leadership, culture issues, Lack of process thinking and process ownership (knowledge), uncompromising management commitment, lack of communication, lack of resources (time, budget, etc.), weak link between the continuous improvement projects and the strategic objectives	Antony et al. 2020

Out of seven quality control tools, Pareto analysis is one of the tools which helps as decision-making tools to identify the vital few factors having a huge impact. The notion of 'vital few, trivial many,' also popularly known as the '80-20' rule, was developed by Italian economist Vilfredo Pareto. The frequency/occurrence of the parameter of interest, i.e., failure factor for the present study, needs to be recorded and the cumulative frequency required to be analyzed. Table 2 depicts the twenty-eight failure factors of Lean Six Sigma from 207 failure factors collected through the literature study, along with their cumulative percentage frequencies.

Table 2 Analysis of failure factors of Lean Six Sigma deployment

Sr. no.	Failure Factors	Frequency	% age of frequency	Cumulative % age of Frequency
1	Lack of top management commitment and involvement	22	10.63	10.63%
2	Lack of synergy of LSS and business strategy	21	10.14	20.77%
3	Lack of awareness of Lean Six Sigma	18	8.70	29.47%
4	Resistance to culture change	17	8.21	37.68%
5	Lack of availability of resources	15	7.25	44.93%
6	Lack of training and education	12	5.80	50.72%
7	Lack of visionary leadership	10	4.83	55.56%

8	Lack of financial resources	9	4.35	59.90%
9	Lack of communication	8	3.86	63.77%
10	Lack of LSS expertise	8	3.86	67.63%
11	Lack of link between LSS and customer needs	8	3.86	71.50%
12	Poor project selection and prioritization	6	2.90	74.40%
13	Wrong perception & selection of LSS as techniques	6	2.90	77.29%
14	High LSS implementation cost	5	2.42	79.71%
15	Lack of a performance measurement system	5	2.42	82.13%
16	Lack of understanding the statistical tool	5	2.42	84.54%
17	Intangibility and unsustainability of the results	5	2.42	86.96%
18	Lack of cross-functional teams	4	1.93	88.89%
19	Establishment LSS dashboard	4	1.93	90.82%
20	Part-time involvement in the LSS project	4	1.93	92.75%
21	Poor selection of employees for belts training	3	1.45	94.20%
22	Lack of interaction with Supplier	3	1.45	95.65%
23	Absence of logistic support	3	1.45	97.10%
24	Lack of standardized practices	2	0.97	98.07%
25	Cost of poor quality	1	0.48	98.55%
26	Fear of failure	1	0.48	99.03%
27	Project management	1	0.48	99.52%
28	Time-consuming	1	0.48	100.00%
	Total	207		

Further, the analysis of the failure factors of Lean Six Sigma deployment based on the Pareto principle is shown in Figure 2. Based on the Pareto analysis, the vital few failure factors, i.e., approximately 28 percent of the total failure factors, impact approximately 60% of the identified failure factors. These vital few failure factors are the lack of top management commitment and involvement, lack of synergy of LSS and business strategy, lack of awareness on LSS, resistance related to culture change, lack of availability of resources, and lack of training and education, lack of visionary leadership, and lack of financial resources.

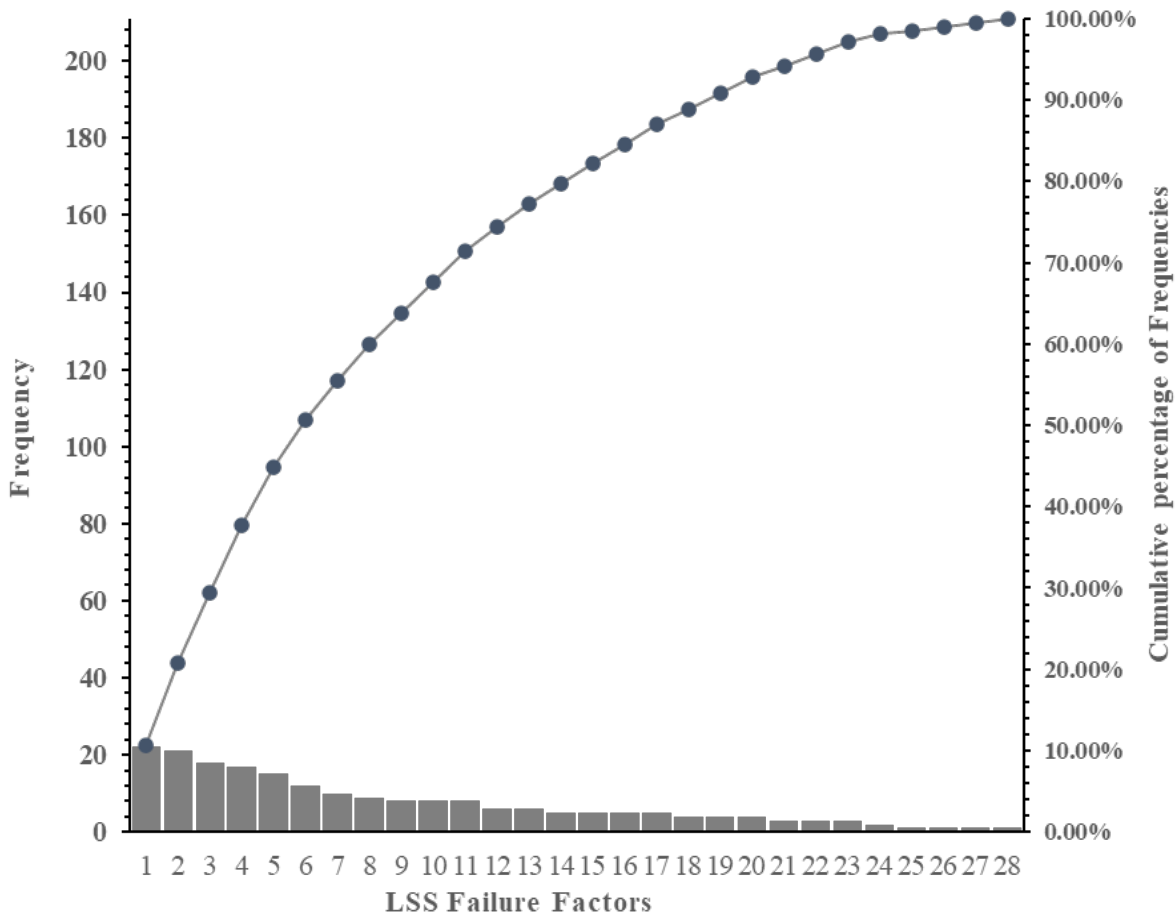


Figure 2. Pareto analysis of failure factor of Lean Six Sigma deployment

5. Managerial Implications

The present study aims to identify and rank the vital failure factors of Lean Six Sigma deployment. The analysis revealed the eight most impactful failure factors of Lean Six Sigma deployment, which are lack of top management commitment and involvement, lack of synergy of LSS and business strategy, lack of awareness on LSS, resistance related to culture change, lack of availability of resources, and lack of training and education, lack of visionary leadership, and lack of financial resources. The research finding indicates the crucial and active role of the top management of any organization in continuous improvement programs as the eight impactful failure factors are directly controlled and influenced by the top management. Further, the findings of the study suggest the strong need for training and education to build awareness about Lean Six Sigma deployment, which may, in turn, reduce the resistance to such a program. These findings will provide significant insights to the managers, practitioners and decision-makers during the Lean Six Sigma deployment to avoid failures.

6. Conclusion

Lean Six Sigma has emerged as a business improvement strategy worldwide in the last fifteen years, which reduces the variation in the products and remove the wastes from the processes. However, Lean Six Sigma deployment is quite challenging and demands lots of effort with attention. This study analyzed the failure factors of Lean Six Sigma deployment and highlighted impactful failure factors. Top management is one of the critical failure factors that emerged from the study. Few other issues from the study are related to resistance to change, awareness and training related to Lean Six Sigma and linking Lean Six Sigma with the vision of the organizations. However, the findings are derived from the reviewed articles during the studies as one limitation.

References

- Albliwi, S.A., Antony, J. and Lim, S.A.H., A systematic review of Lean Six Sigma for the manufacturing industry, *Business Process Management Journal*, vol. 21, no. 3, pp. 665–691, 2015
- Alhuraish, I., Robledo, C. and Kobi, A., A comparative exploration of lean manufacturing and six sigma in terms of their critical success factors, *Journal of Cleaner Production*, vol. 164, pp. 325–337, 2017
- Alkunsol, W.H., Sharabati, A.A.A., AlSalhi, N.A. and El-Tamimi, H.S., Lean Six Sigma effect on Jordanian pharmaceutical industry's performance, *International Journal of Lean Six Sigma*, vol. 10 no. 1, pp. 23–43, 2019
- Antony, J., Ghadge, A., Ashby, S.A. and Cudney, E.A. (2018), Lean Six Sigma journey in a UK higher education institute: a case study, *International Journal of Quality & Reliability Management*, vol. 35 no. 2, pp. 510–526
- Antony, J., Gupta, S., Sunder M, V. and Gijo, E.V., Ten commandments of Lean Six Sigma: a practitioners' perspective, *International Journal of Productivity and Performance Management*, vol. 67 no. 6, pp. 1033–1044, 2018
- Ashkenas, R., It's time to rethink continuous improvement, *Harvard Business Review*, 2012 Available: <https://hbr.org/2012/05/its-time-to-rethink-continuous>, Accessed on May 21, 2022
- Breyfogle, F.W., *Implementing Six Sigma*, 2nd Edition, John Wiley & Sons, Inc., New Jersey, 2003
- Brue, G., *Six Sigma for Managers*, 2nd Edition, McGraw-Hill, USA, 2015
- Coronado, R.B. and Antony, J., Critical success factors for the successful implementation of six sigma projects in organisations, *TQM Magazine*, vol. 14 no. 2, pp. 92–99, 2002
- Danese, P., Manfè, V. and Romano, P., A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions, *International Journal of Management Reviews*, vol. 20 no. 2, pp. 579–605, 2018
- Eckes, G., *The Six Sigma Revolution: How General Electric and Others Turned Process into Profits*, John Wiley & Sons, Inc, 2001
- Edgeman, R.L. and Dugan, J.P., Six Sigma from products to pollution to people, *Total Quality Management and Business Excellence*, vol. 19 no. 1–2, pp. 1–9, 2008
- George, M.L., *Lean Six Sigma : Combining Six Sigma Quality with Lean Production Speed*, McGraw-Hill, 2002
- Gupta, S., Modgil, S. and Gunasekaran, A., Big data in lean six sigma: a review and further research directions, *International Journal of Production Research*, vol. 58 no. 3, pp. 947–969, 2020
- Hahn, R., Doganaksoy, N. and Hoerl, G., The evolution of six sigma, *Quality Engineering*, vol. 12 no. 3, pp. 317–326, 2000
- Harry, M.J., *The Nature of Six sigma Quality*, 1st Edition, Motorola Inc., Arizona, 1987
- Harry, M.J., Six Sigma: A Breakthrough Strategy for Profitability, *Quality Progress*, vol. 31 no. 5, pp. 60–64, 1998
- Hoerl, R.W., Six Sigma Black Belts: What Do They Need to Know?, *Journal of Quality Technology*, vol. 33 no. 4, pp. 391–406, 2001
- Holweg, M., The genealogy of lean production, *Journal of Operations Management*, vol. 25 no. 2, pp. 420–437, 2007
- Krafcik, J.K.F., Triumph of the lean production system, *Sloan Management Review*, vol. 30 no. 1, pp. 41–52, 1988
- Kumar, M., Antony, J. and Tiwari, M.K., Six Sigma implementation framework for SMEs-a roadmap to manage and sustain the change, *International Journal of Production Research*, vol. 49 no. 18, pp. 5449–5467, 2011
- Kwak, Y.H. and Anbari, F.T., Benefits, obstacles, and future of six sigma approach, *Technovation*, vol. 26 no. 5–6, pp. 708–715, 2006
- Lande, M., Shrivastava, R.L. and Seth, D., Critical success factors for Lean Six Sigma in SMEs (small and medium enterprises), *The TQM Journal*, vol. 28 no. 4, pp. 613–635, 2016
- Laureani, A. and Antony, J., Critical success factors for the effective implementation of Lean Sigma, *International Journal of Lean Six Sigma*, vol. 3 no. 4, pp. 274–283, 2012
- Laureani, A. and Antony, J., Leadership and Lean Six Sigma: a systematic literature review, *Total Quality Management & Business Excellence*, Taylor & Francis, vol. 30 no. 1–2, pp. 53–8, 2019
- McLean, R.S., Antony, J. and Dahlgaard, J.J., Failure of Continuous Improvement initiatives in manufacturing environments: a systematic review of the evidence, *Total Quality Management and Business Excellence*, vol. 28 no. 3–4, pp. 219–237, 2017
- Null, G., Cross, J.A. and Brandon, C., Effects of Lean Six Sigma in program management, *Journal of Manufacturing Technology Management*, vol. 31 no. 3, pp. 572–598, 2019
- Ohno, T., *Toyota Production System Beyond Large-Scale Production*, Productivity Press, 1988
- Panayiotou, N.A. and Stergiou, K.E., A systematic literature review of lean six sigma adoption in European organizations, *International Journal of Lean Six Sigma*, Vol. 12 No. 2, pp. 264–292, 2021
- Park, S.H., *Six Sigma for Quality and Productivity Promotion*, Asian Productivity Organization, Asian Productivity Organization, Tokyo, Japan, 2003

- Patel, A.S. and Patel, K.M., Critical review of literature on Lean Six Sigma methodology, *International Journal of Lean Six Sigma*, vol. 12 no. 3, pp. 627–674, 2021a
- Patel, A.S. and Patel, K.M., Prioritization of Lean Six Sigma Success Factors using Pareto Analysis, *IOP Conference Series: Materials Science and Engineering*, vol. 1070, pp. 012133, 2021b
- Raja Sreedharan, V. and Raju, R., A systematic literature review of Lean Six Sigma in different industries, *International Journal of Lean Six Sigma*, vol. 7 no. 4, pp. 430–466, 2016
- Rathi, R., Kumar, A. and Khanduja, D., Identification and Prioritization Lean Six Sigma Barriers in MSMEs, *Journal of Physics: Conference Series*, vol. 1240 no. 1, pp. 012062, 2019
- Rathi, R., Singh, M., Kumar Verma, A., Singh Gurjar, R., Singh, A. and Samantha, B., Identification of Lean Six Sigma barriers in automobile part manufacturing industry, *Materials Today: Proceedings*, vol. 50 no. 5, pp. 728–735, 2022
- Raval, S.J., Kant, R. and Shankar, R., Lean Six Sigma implementation: modelling the interaction among the enablers, *Production Planning & Control*, vol. 29 no. 12, pp. 1010–1029, 2018
- Ruben, R. Ben, Vinodh, S. and Asokan, P., Lean Six Sigma with environmental focus: review and framework, *International Journal of Advanced Manufacturing Technology*, vol. 94 no. 9–12, pp. 4023–4037, 2018
- Sambhe, R.U. and Dalu, R.S., “An empirical investigation of Six Sigma implementation in medium scale Indian automotive enterprises”, *International Journal of Productivity and Quality Management*, vol. 8 no. 4, p. 480–501, 2011
- Shamsi, M.A. and Alam, A., Exploring Lean Six Sigma implementation barriers in Information Technology industry, *International Journal of Lean Six Sigma*, vol. 9 no. 4, pp. 523–542, 2018
- Sheridan, J.H., Lean Sigma Synergy, *Industry Week*, vol. 249 no. 17, pp. 81–82, 2000
- Shokri, A., Quantitative analysis of Six Sigma, Lean and Lean Six Sigma research publications in last two decades, *International Journal of Quality and Reliability Management*, vol. 34 no. 5, pp. 598–625, 2017
- Singh, M. and Rathi, R., Empirical Investigation of Lean Six Sigma Enablers and Barriers in Indian MSMEs by Using Multi-Criteria Decision Making Approach, *Engineering Management Journal*, vol. 34, no. 3, pp. 475–496, 2022
- Snee, R.D., Lean Six Sigma – getting better all the time, *International Journal of Lean Six Sigma*, vol. 1 no. 1, pp. 9–29, 2010
- Sony, M., Naik, S. and Therisa, K.K., Why do organizations discontinue Lean Six Sigma initiatives?, *International Journal of Quality & Reliability Management*, vol. 36 no. 3, pp. 420–436, 2019
- Sreeram, T.R. and Thondiyath, A., Combining Lean and Six Sigma in the context of Systems Engineering design”, *International Journal of Lean Six Sigma*, vol. 6 no. 4, pp. 290–312, 2015
- Sunder M, V. and Antony, J., A conceptual Lean Six Sigma framework for quality excellence in higher education institutions, *International Journal of Quality & Reliability Management*, vol. 35 no. 4, pp. 857–874, 2018
- Tjahjono, B., Ball, P., Vitanov, V.I., Scorzafave, C., Nogueira, J., Calleja, J., Minguet, M., Six sigma: A literature review, *International Journal of Lean Six Sigma*, vol. 1 no. 3, pp. 216–233, 2010
- Tranfield, D., Denyer, D. and Smart, P., Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review, *British Journal of Management*, vol. 14 no. 3, pp. 207–222, 2003
- Walter, O.M.F.C. and Paladini, E.P., Lean Six Sigma in Brazil: a literature review, *International Journal of Lean Six Sigma*, vol. 10 no. 1, pp. 435–472, 2019
- Wang, C.H., Chen, K.S. and Tan, K.H., Lean Six Sigma applied to process performance and improvement model for the development of electric scooter water-cooling green motor assembly, *Production Planning & Control*, vol. 30 no. 5–6, pp. 400–412, 2019
- Womack, J.P., Jones, D.T. and Roos, D., *The Machine That Changed the World*, New York, 1990
- Yadav, G., Seth, D. and Desai, T.N., Application of hybrid framework to facilitate lean six sigma implementation: a manufacturing company case experience, *Production Planning & Control*, vol. 29 no. 3, pp. 185–201, 2018
- Yadav, V., Gahlot, P., Kaswan, M.S. and Rathi, R., Green Lean Six Sigma critical barriers: exploration and investigation for improved sustainable performance”, *International Journal of Six Sigma and Competitive Advantage*, vol. 13 no. 1–3, pp. 101–119, 2021
- Yamamoto, K., Milstead, M. and Lloyd, R., A Review of the Development of Lean Manufacturing and Related Lean Practices: The Case of Toyota Production System and Managerial Thinking, *International Management Review*, vol. 15 no. 2, pp. 21–40, 2019
- Zare Mehrjerdi, Y., Six-Sigma: methodology, tools and its future, *Assembly Automation*, vol. 31 no. 1, pp. 79–88, 2011.

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