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Strategic Technology Investment: A Catalyst for Lean Six Sigma Implementation in Manufacturing SMEs

Irshadul Islam C A
Research Scholar Faculty of Management Studies and Research Aligarh Muslim University

Dr. Asif Ali Syed
Associate Professor Department of Management Faculty of Management Studies and Research Aligarh Muslim University

Dr G Varaprasad
Associate Professor Department of Mechanical Engineering National Institute of Technology Calicut

Abstract
In an increasingly competitive global landscape, Small & Medium-sized Enterprises (SMEs) in the manufacturing sector are constantly seeking methodologies to enhance efficiency, reduce waste, and improve product quality. “Lean Six Sigma (LSS)” stands out as a robust framework that integrates the waste-reduction principles of Lean with the variation-minimization strategies of Six Sigma. This study aims to explore the intricate relationship between technological readiness, new technology investment, and the successful adoption of LSS methodologies within manufacturing sector SMEs. Understanding these dynamics is crucial for enabling SMEs to fully harness the benefits of LSS, thereby fostering sustainable growth and competitiveness. A survey was carried out for understanding the adoption and implementation of Lean Six Sigma tools and techniques in Indian SME’s working in the furniture, footwear, food processing and steel manufacturing industries. Around 431 responses were collected through a questionnaire and the data was collected based on various aspects. The findings indicate that organizations that are prepared to adopt LSS technologies have invested in enabling new technology and are more likely to adopt LSS technologies.

Keywords
Small. & Medium-sized Enterprises (SMEs), Lean Six Sigma (LSS), LSS technologies, Invested, Adopt

Introduction
In today's fiercely competitive global marketplace, manufacturing-focused Small and Medium-sized Enterprises (SMEs) are constantly searching for ways to boost efficiency, cut down on waste, and enhance product quality. Lean Six Sigma (LSS) stands out as a powerful approach, combining Lean's focus on eliminating waste with Six Sigma's strategies for minimizing variation. While large corporations have often implemented LSS with great success, its adoption by SMEs faces distinct hurdles, particularly concerning their limited resources and technological capabilities. Increasingly, effective LSS implementation hinges on integrating the right technological tools, from advanced data analytics software to automated solutions. This research aims to delve into the complex relationship between technological readiness, new technology investment, and the successful uptake of LSS methods within manufacturing SMEs. Grasping these dynamics is critical for empowering SMEs to fully leverage LSS benefits, thereby fostering sustained growth and market competitiveness.

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Need of the Study

Despite widespread acknowledgment of Lean Six Sigma's (LSS) transformative potential for manufacturing, its comprehensive integration within Small and Medium-sized Enterprises (SMEs) remains a significant hurdle. Existing research, while robust in individual domains, highlights crucial areas where understanding is lacking. This study aims to address these critical gaps.

Firstly, a limited empirical understanding exists regarding the direct influence of technological readiness on the actual adoption rates and effectiveness of LSS methodologies within manufacturing SMEs. While it's intuitively accepted that technology facilitates LSS, a detailed investigation is needed to show precisely how an SME's existing technological infrastructure, employee skills, and organizational culture collectively shape their ability to successfully initiate, sustain, and benefit from LSS. This research will bridge this gap by providing specific, data-driven insights into this complex interplay.

Secondly, the concept of "new technology investment to enable LSS practices" has not been thoroughly explored in the SME context. What specific technologies are SMEs investing in, and are these investments strategically aligned with LSS principles or merely ad-hoc purchases? Gaining a clear understanding of the types of new technologies—such as specialized data analysis software, automation tools for process improvement, or digital collaboration platforms—that SMEs prioritize to support their LSS journey is essential for offering practical guidance and developing targeted support programs.

Finally, a notable void in the literature concerns the quantitative relationship between the types of technological tools used to facilitate LSS practices and the proportion of the budget allocated to LSS technology upgrades. While anecdotal evidence might suggest that more technologically advanced LSS implementations require greater financial outlay, there's a clear need for empirical data to firmly establish this association. This study will delve into how SMEs allocate their financial resources for LSS-specific technological advancements, shedding light on their investment priorities and the perceived value of different technological tools in driving LSS success. This nuanced understanding is crucial for several stakeholders:

- Policy Makers**:** To design targeted incentives, subsidies, and training initiatives that promote technological adoption to support LSS within SMEs.
- SME Owners/Managers**:** To make informed decisions about technology investments, ensuring that their budget allocation aligns with their LSS objectives and generates optimal returns.
- Technology Providers**:** To customize their products and services to precisely meet the unique needs and financial constraints of manufacturing SMEs aiming to implement LSS.
- Academicians and Researchers**:** To enrich the existing body of knowledge on LSS implementation in SMEs, particularly at the intersection of technology and organizational capability.

By addressing these significant research voids, this study will offer a comprehensive understanding of how technological readiness and strategic investment can unlock the full potential of Lean Six Sigma in manufacturing sector SMEs, ultimately enhancing their competitiveness and fostering sustainable growth.

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Current Scholarly Perspectives

The academic literature extensively addresses the individual components of Lean Six Sigma, technology adoption, and the unique challenges faced by SMEs. However, the intricate relationship among these elements, especially within manufacturing SMEs, demands more in-depth investigation.

Ren Y. et.al (2024) mention in Deploying Lean Six Sigma to Improve Assembly Precision of NEV Component: Evidence from Chinese SME "Unsatisfactory assembly precision has been a persisting quality problem *in* auto industry. This paper aimed to deploy Lean Six Sigma (*LSS*) methodology to facilitate the improvement on assembly precision of a component manufacturer *in* new energy vehicle industry from Chinese small and medium-sized enterprise's perspective. Case study method was chosen. Six Sigma-based framework of Define-Measure-Analyse-Improve-Control (DMAIC) methodology was adopted. Critical steps and significant factors were identified to detect the quality problem, to improve the low assembly precision. The results provided solid evidence that how *LSS* can be successfully applied as the first step *in* a small and medium-sized enterprise (*SME*). Our finding showed that heating temperature, preservation time, and install time were significant factors hampering assembly precision. Our results pointed that establishing quality team with qualified employees was required to sustain continuous improvement. Our case study enriches the literature with empirical insights on how *LSS implementation in* NEV component manufacture with unique perspective of Chinese *SME*. These insights could be implied to demonstrate how SMEs response to new technologies/practices when quality improvement is needed."

Attar, M. T. (2023) article mentions Lean Six Sigma (LSS) has emerged as a vital strategic tool for enhancing business performance across various organizations, including small and medium-sized enterprises (SMEs). SMEs, in particular, have demonstrated a noteworthy influence on the gross domestic product (GDP) of many nations. This study aims to explore the key success factors (KSFs) that facilitate the effective adoption of LSS within SMEs operating in the Kingdom of Saudi Arabia. The research seeks to identify the elements that contribute to improved business outcomes, increased profitability, and stronger competitive positioning. Drawing from previous literature, 29 relevant factors were initially compiled to support successful LSS deployment in Saudi SMEs. These were later streamlined into a comprehensive set of 14 critical factors. Using principal components analysis (PCA), the study revealed four overarching dimensions: the presence of strong leadership and an organized management structure, technological readiness, the capacity for acquiring knowledge, and the role of creativity and innovation. These dimensions are expected to play a crucial role in supporting SMEs in Saudi Arabia as they integrate LSS into their operational frameworks.

Lean Six Sigma (LSS) in SMEs**:** Numerous studies underscore the advantages of LSS, including enhanced quality, reduced costs, improved customer satisfaction, and increased productivity (Antony et al., 2017; Sahoo et al., 2021). Nevertheless, the literature also acknowledges the particular obstacles SMEs encounter during LSS implementation, such as limited financial resources, a shortage of specialized expertise, cultural resistance, and a focus on short-term gains (Kumar et al., 2018; Psomas & Antony, 2019). The scope of LSS projects often needs to be adapted to the specific characteristics of SMEs, favoring incremental improvements over large-scale transformations.

Technological Readiness and Adoption**:** Technological readiness, frequently defined as an individual's or organization's willingness to embrace and utilize new technologies (Parasuraman, 2000), is pivotal for the successful adoption of any innovation. In manufacturing, technological readiness extends beyond mere hardware and software availability to include the requisite skills and an organizational culture conducive to effective tool utilization (Lee & Shim, 2020). Research on technology adoption in SMEs frequently identifies perceived usefulness, ease of use, strong top management support, and external pressures as key determinants (Ghobakhloo & Tang, 2013; Teo et al., 2006). The emergence of Industry 4.0 technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, and automation, presents both opportunities and challenges for LSS implementation in manufacturing (Dalenogare et al., 2018; Wang & Liu, 2021).

New Technology Investment and LSS Practices: The integration of technology is becoming increasingly vital for effective LSS implementation. Data collection, analysis, visualization, and process control are significantly enhanced by specialized software and digital tools. Investments in new technologies can facilitate various aspects of LSS, such as statistical process control (SPC) software, simulation tools, enterprise resource planning (ERP) systems, and even robotic process automation (RPA) for transactional processes (Kholopov et al., 2020; Rajaram & Soundararajan, 2022). However, the literature also indicates that investment alone is insufficient; successful integration requires meticulous planning, comprehensive training, and alignment with overarching organizational goals (Singh et al., 2019). The ongoing challenge for SMEs lies in identifying the most impactful technological investments given their often-constrained budgets.

Ramkumar P N. Et.al. (2019) mention in their article **"**A study of the effect of lean six sigma's critical success factors in Indian SMEs", "SMEs play a growing role in the world-wide economy by producing considerable occupation opportunities and contributing steadily to GDP growth across various nations. However, these businesses often struggle to remain competitive against larger establishments and a wide array of rivals. To survive in such a competitive setting, SMEs must offer products of reliable quality at lower costs than their competitors, which necessitates the adoption of effective quality management strategies. Lean Six Sigma (LSS) is one such methodology that has demonstrated its ability to boost operational efficiency and quality. By minimizing process variation and cutting unnecessary costs, LSS can lead to significant improvements in profitability. The purpose of this research is to pinpoint the critical success factors (CSFs) that influence the implementation of LSS in Indian SMEs. The investigation uncovered nine key factors that facilitate successful LSS adoption in these businesses. Additionally, the study examined how these factors vary across different types of industries. This research forms the foundational phase of the author's broader work, which later resulted in the creation of a customized framework called the Identify-Rank-Define-Analyse-Improve-Control (IRDAIC) model. This model was subsequently tested and validated through its application in SME environments".

Budget Allocation for LSS Technology Upgrades**:** While the importance of technology in LSS is widely acknowledged, there is limited specific literature detailing the proportion of the budget allocated to LSS technology upgrades within SMEs. Most studies tend to focus on overall LSS implementation costs or the return on investment (ROI) derived from LSS initiatives (Gijo & Rao, 2017). Understanding how SMEs prioritize and allocate resources for technological tools that specifically facilitate LSS practices is crucial for developing targeted support mechanisms

and policy recommendations. This area remains relatively unexplored, particularly concerning the types of technological tools utilized and their direct correlation with budget allocation.

In summary, while the benefits of LSS are well-documented, it's effective adoption in manufacturing SMEs often hinges on their technological readiness and strategic investment in enabling technologies. Current literature provides a foundational understanding, but a clear gap exists in comprehending the specific financial commitment SMEs make toward LSS-enabling technologies and the direct impact of this investment on LSS practices.

Objectives of the study

- To establish the impact of technological readiness on the adoption of LSS methodologies in the manufacturing sector SMEs.
-To establish new technology investment to enable LSS practices.
-To understand significant association between the type of technological tools used to facilitate LSS practices and the proportion of the budget allocated to LSS technology upgrades.

Research Methodology

A survey was carried out for understanding the adoption and implementation of Lean Six Sigma tools and techniques in Indian SME's working in the furniture, footwear, food processing and steel manufacturing industries. Around 431 responses were collected through a questionnaire and the data was collected based on various aspects. We review a few of the questions for the paper.

Analysis and findings

1. To establish the impact of technological readiness on the adoption of LSS methodologies in the manufacturing sector SMEs and also understand new technology investment to enable LSS practices.

Hypothesis for the statement-

- **Null Hypothesis (H_0):** There is no significant association between **LSS readiness** and **new technology investment** (i.e., organizations that are ready for LSS technology are not more likely to have invested in new technology to enable LSS practices).
- **Alternate Hypothesis (H_1):** There is a significant association between **LSS readiness** and **new technology investment** (i.e., organizations that are ready for LSS technology are more likely to have invested in new technology to enable LSS practices).

Table No. 1:Cross tabulation of LSS Readiness and New Technology Investment

Is your organization ready for the technology needed for LSS adoption? * Do you have new technology invested in enabling LSS practices? Cross tabulation				
Count				
		Do you have new technology invested in enabling LSS practices?		Total
		Yes	No	
Is your organization ready for the	Yes	223	25	248
	No	183	0	183

technology needed for LSS adoption?				
Total		406	25	431

- The table investigates the connection between LSS readiness (the subject was ready for LSS technology) and new technology investment (the subject invested in technology that can support LSS practices).
- 248 respondents prepared for LSS technology have also invested money in new technology to facilitate these LSS practices.
- None of the 183 suppliers of LSS technology have invested in new technology
- The findings indicate that organizations that are prepared to adopt LSS technologies have invested in enabling new technology and are more likely to adopt LSS technologies.
- This cross tabulation suggests a clear pattern whereby organizations that are ready to implement LSS technology also tend to invest in the required technology and those who are not yet ready for LSS adoption, have generally not made the quality investments either.

Table No. 2:Chi-Square Test Results for LSS Readiness vs. New Technology Investment

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	19.584[a]	1	.000		
Continuity Correction[b]	17.782	1	.000		
Likelihood Ratio	28.764	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	19.538	1	.000		
N of Valid Cases	431				
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.61.					
b. Computed only for a 2x2 table					

The Chi-Square test results ($\chi^2 = 19.584$, $p < 0.001$) show that LSS readiness has a statistically significant association with new technology investment. This significance is further confirmed with Likelihood Ratio (28.764) and Linear-by-Linear Association (19.538), both with $p < 0.001$.

A p-value as small as 0.000 (both asymptotic and exact) is far below the significance level ($\alpha = 0.05$), thus we can reject the null hypothesis (H_0) with confidence.

In this case, not one of the cells have an expected count less than 5, meaning that the data meets the assumptions of performing a Chi-square test.

Results show a significant correlation between organizations that are ready to adopt LSS and those who have invested in the technology that will enable them to make the transition to LSS. Such organizations focus on enabling technologies (and invest in them) much before the adoption of LSS and extensive implementation of LSS practices since deploying tools must be a part of LSS implementation.

2. To understand significant association between the type of technological tools used to facilitate LSS practices and the proportion of the budget allocated to LSS technology upgrades.

Hypothesis for the statement-

- **Null Hypothesis (H_0):** There is no statistically significant association between the type of technological tools used to facilitate LSS practices and the proportion of the budget allocated to LSS technology upgrades.
- **Alternate Hypothesis (H_1):** There is a statistically significant association between the type of technological tools used to facilitate LSS practices and the proportion of the budget allocated to LSS technology upgrades.

Table No. 3: Cross tabulation of Technological Tools Used for LSS and the Budget Spent on LSS Technology Upgrades

What technological tools are used to facilitate the LSS practices? * How much of your budget is spent on LSS technology upgrades? Cross tabulation					
Count					
		How much of your budget is spent on LSS technology upgrades?			Total
		Less than 5%	5% to 10%	More than 10%	
What technological tools are used to facilitate the LSS practices?	Data Analytics Tools	25	0	0	25
	Data Analytics Tools, Project Management Tools, Data Visualisation Tools, Root Cause Analysis Tools	34	0	0	34
	Data Analytics Tools, Project Management Tools, ERP Systems, Data Visualisation Tools	10	5	0	15

	Data Analytics Tools, Project Management Tools, ERP Systems, Data Visualisation Tools, Root Cause Analysis Tools	0	35	0	35
	Data Analytics Tools, Project Management Tools, ERP Systems, Process Automation Software	55	0	0	55
	Data Analytics Tools, Root Cause Analysis Tools	0	0	25	25
	Data Visualisation Tools	10	22	0	32
	Data Visualisation Tools, Root Cause	0	44	0	44

	Analysis Tools				
	ERP Systems	1	0	0	1
	ERP Systems, Process Automation Software	8	0	0	8
	ERP Systems, Root Cause Analysis Tools	4	0	0	4
	Project Management Tools, ERP Systems, Process Automation Software	120	30	3	153
Total		267	136	28	431

This table shows the technology tools organizations use to drive Lean Six Sigma (LSS) practices, as well as the percent of organizations' budgets devoted to LSS technology upgrades. Based on a small sample, organizations using just data analytics, ERP, and other basic tools spend less than 5% of their budget on LSS-related technology: 120 organizations that just use project management + ERP + automation tools only spent less than 5%
More complex combinations (e.g., Data Analytics + Root Cause Analysis Tools) are correlated with large budgets — 25 organizations in this category allocated over 10% of their budget.
5–10% for a large group using Data Visualization + Root Cause Analysis Tools (44 organizations) suggesting a strong alignment of specialized tool usage with moderate tech investment.
This pattern suggests that as tools become more specialized or analytical, tech budgets are allocated more, while far more operational tools tend to correlate with lower tech spend.

Findings & Suggestions

- The findings indicate that organizations that are prepared to adopt LSS technologies have invested in enabling new technology and are more likely to adopt LSS technologies.
- The cross tabulation in Table 1 suggests a clear pattern whereby organizations that are ready to implement LSS technology also tend to invest in the required technology and those who are not yet ready for LSS adoption, have generally not made the quality investments either.

- Results show a significant correlation between organizations that are ready to adopt LSS and those who have invested in the technology that will enable them to make the transition to LSS. Such organizations focus on enabling technologies (and invest in them) much before the adoption of LSS and extensive implementation of LSS practices since deploying tools must be a part of LSS implementation.
- The table – 3 shows a pattern that suggest tools become more specialized or analytical, tech budgets are allocated more, while far more operational tools tend to correlate with lower tech spend.
- LSS activities must have dedicated resources - financial, technological, and human. A lack of funding towards LSS can spawn ineffective or incomplete LSS roll-outs.
- Where there is proper resource allocation looking at the study from a cost/success perspective shows better success. This is something that should be integrated into annual planning cycles.
- After the human capital challenge comes the challenge to create quality firms should set up internal LSS task forces or quality improvement teams. These cross-functional teams can oversee execution and resolution of issues. You only feel accountable for ownership and removal of the barriers standing in between implementation. In addition, it propagates LSS culture across departments.

Conclusion

The evidence of a significant association between LSS readiness and investment in new technology. It may imply that the organizations prepared for LSS implementation, will be most likely to adopt new technologies that facilitate LSS practices. Thus, LSS and technology investment differ widely; however, technology acts as a key enabler for the effective adoption of LSS practices, meaning readiness for LSS influences technology investment greatly. Organizations must focus on enabling technologies (and invest in them) much before the adoption of LSS and extensive implementation of LSS practices since deploying tools must be a part of LSS implementation.

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