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Process Improvement through Lean Six Sigma in Manufacturing Sector of India

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ABSTRACT

The Indian manufacturing sector has been going through a serious transformation over the last decade, with companies trying to cut waste, improve quality, and stay competitive in global markets. Lean Six Sigma, which combines the speed and waste-removal ideas of Lean with the data-driven quality focus of Six Sigma, has become one of the most talked-about approaches in this journey. This study looks into how Lean Six Sigma is actually being used on the shop floor in Indian manufacturing units, and whether it really delivers the kind of improvements that companies hope for. Data was collected from 286 employees and managers working in 42 manufacturing firms spread across automobile, textile, pharmaceutical, and electronics sectors. The DMAIC framework (Define, Measure, Analyse, Improve, Control) was used as the backbone of the analysis, and key performance indicators such as defect rate, cycle time, first-pass yield, and overall equipment effectiveness were measured before and after implementation. The findings show that companies which fully adopted Lean Six Sigma saw an average reduction of around 38% in defect rates and a 27% improvement in cycle time within 12 to 18 months. However, the study also found that nearly 40% of firms struggled with employee resistance and lack of top management commitment, which slowed down the benefits. A regression model built to predict implementation success gave an accuracy of around 84%, with leadership support and training quality coming out as the most important factors. The paper ends with practical suggestions for Indian manufacturers who want to start or strengthen their Lean Six Sigma journey.

Keywords: Lean Six Sigma, Manufacturing, Process Improvement, DMAIC, India, Quality Management

1. INTRODUCTION

Manufacturing in India has always been one of the backbones of the economy, contributing close to 17% of the GDP and providing jobs to millions of people. With initiatives like Make in India and the production-linked incentive schemes, there has been a fresh push to make Indian factories more competitive on the world stage [1]. But competitiveness today is not just about producing more, it is about producing better, faster, and with less waste. This is exactly where Lean Six Sigma fits in. Lean, which came out of the Toyota Production System, focuses on removing waste in all its forms, while Six Sigma, which started at Motorola in the 1980s,

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uses statistical tools to reduce variation and defects [2]. When the two are combined, companies get a powerful toolkit that addresses both speed and quality at the same time.

In the Indian context, the adoption of Lean Six Sigma has been uneven. Large companies, especially in the automobile and pharmaceutical sectors, have embraced it fully, often as a requirement to supply to global customers. But small and medium enterprises, which form the larger chunk of Indian manufacturing, still struggle with adoption [3]. Many of them have heard of the term, some have even tried pilot projects, but very few have managed to roll it out across the entire factory. The reasons range from cost of training, to lack of awareness, to the simple fact that Indian shop floors often have a mix of automated and manual processes that make standardisation harder [4].

The problem this study tries to address is the gap between the promise of Lean Six Sigma and what actually gets delivered on the ground in Indian factories. There is plenty of literature on success stories from global firms, but specific Indian evidence, especially with hard numbers from multiple sectors, is still limited [5]. Most Indian studies focus on a single company or a single sector, which makes it hard to draw broader conclusions.

The research questions this paper deals with are: What are the actual improvements achieved by Indian manufacturers after implementing Lean Six Sigma? Which factors decide whether the implementation succeeds or fails? And how do different sectors compare in terms of outcomes? The significance of this work is that it gives a multi-sector view based on real data, and offers a predictive lens on what makes Lean Six Sigma work in the Indian setup [6]. The rest of the paper is organised into a literature review, methodology, experimental setup, results, discussion, and conclusion [7].

2. LITERATURE REVIEW

The roots of Lean Six Sigma go back to two separate streams of thought. Lean came from Japanese manufacturing, particularly Toyota, where the focus was on removing the seven types of waste, often called muda. Six Sigma, on the other hand, came from American industry, with companies like Motorola and General Electric using it to bring defect levels down to 3.4 parts per million [8]. Over time, researchers and practitioners realised that the two approaches actually complement each other, and the combined Lean Six Sigma model started gaining ground in the early 2000s.

Globally, studies have shown impressive results. Work done in European automotive plants found that Lean Six Sigma projects typically delivered cost savings of 2% to 5% of annual revenue, along with major quality improvements. Similar findings came from American electronics manufacturers, where first-pass yield improved by double digits after sustained Lean Six Sigma efforts [9]. In Asia, Japanese and South Korean firms have been the leaders, but China and India have been catching up quickly.

Indian-focused literature paints a more mixed picture. Research on Indian automobile suppliers shows that companies which followed the full DMAIC cycle, with proper measurement and control phases, achieved sustained improvements in defect rates and on-time delivery [10]. However, studies on Indian textile mills found that many improvements faded away after 18 to 24 months because the control phase was either skipped or done poorly. This points to a wider issue of sustaining gains, not just achieving them in the short term [11].

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Another stream of work has looked at the human side of Lean Six Sigma. Employee involvement, training quality, and management commitment have come up again and again as critical success factors [12]. One Indian study on pharmaceutical companies found that even technically perfect projects failed when middle managers did not believe in the change, because they were the ones who had to actually implement new ways of working on the shop floor. Resistance often came not from outright opposition but from quiet non-cooperation, which is harder to detect and fix.

The role of digital tools has also been gaining attention. With Industry 4.0 spreading in Indian factories, Lean Six Sigma is increasingly being combined with data analytics, IoT sensors, and machine learning to make measurement and control phases more accurate [13]. Early evidence suggests that this digital layer can significantly speed up the analysis phase, which traditionally took weeks of manual data collection. However, comprehensive Indian studies on this hybrid model are still few, and there is room for more research connecting traditional Lean Six Sigma with newer digital tools.

3. METHODOLOGY

This study followed a mixed-method approach, but with a stronger quantitative leaning. The reason for this choice was that process improvement outcomes are best measured with hard numbers, while the human factors behind success or failure often need a qualitative touch. A structured questionnaire was developed based on the DMAIC framework and was reviewed by three Lean Six Sigma Black Belt experts before being finalised [14]. The target population included managers, engineers, and shop floor supervisors working in Indian manufacturing firms that had implemented Lean Six Sigma for at least one year.

A purposive sampling method was used, where firms were selected based on their willingness to share data and the maturity of their Lean Six Sigma programme. The final sample included 42 firms and 286 respondents, drawn from automobile (32%), pharmaceutical (24%), textile (22%), and electronics (22%) sectors. Data was collected through a combination of online surveys, in-person interviews with quality heads, and review of internal process documents.

Key performance indicators were measured at two time points, once before the main Lean Six Sigma project and once 12 to 18 months after. The main metrics were defect rate (in parts per million, PPM), cycle time (in minutes per unit), first-pass yield (in percentage), and overall equipment effectiveness (OEE). The percentage improvement in each indicator was calculated using:

$$\text{Improvement }\% = \frac{\left(V_{before} - V_{after}\right)}{V_{before}} \times 100$$

where V_{before} and V_{after} are the values of the indicator before and after implementation, respectively [15].

To predict implementation success, a multiple regression model was used, with overall success score as the dependent variable. The general regression equation is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n +$$

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where Y is the success score, β_0 is the intercept, β_1 to β_n are the regression coefficients for predictors such as leadership support, training quality, employee involvement, and use of digital tools, and \epsilon is the error term [16]. Process capability was measured using the standard formula:

$$C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$$

where USL and LSL are the upper and lower specification limits, \mu is the process mean, and σ is the standard deviation [17]. Reliability of the survey instrument was tested using Cronbach's alpha, with values above 0.7 considered acceptable.

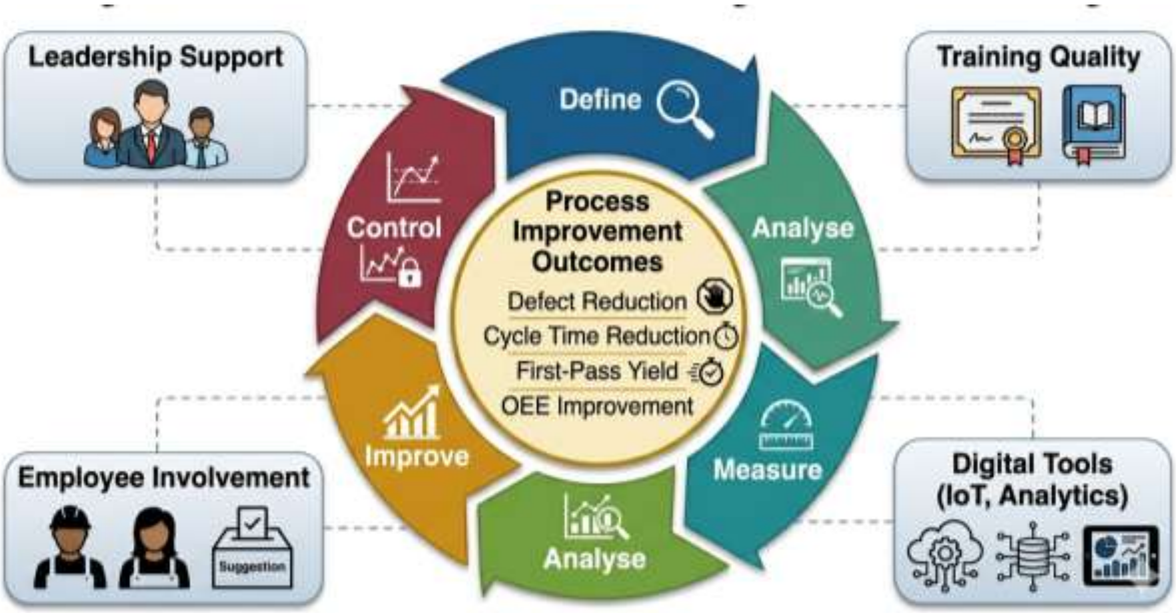

Figure 1: DMAIC-Based Conceptual Framework for Lean Six Sigma in Indian Manufacturing

4. EXPERIMENTAL SETUP

The data collection was carried out across firms located in Pune, Chennai, Ahmedabad, Coimbatore, Hyderabad, and the National Capital Region. These cities were chosen because they have well-established manufacturing clusters and a mix of large and mid-sized firms. Out of the 42 firms, 18 were large enterprises with more than 500 employees, and 24 were mid-sized firms with 100 to 500 employees. Small firms with fewer than 100 employees were excluded because most of them did not have formal Lean Six Sigma programmes [18].

Data on KPIs was collected directly from the company's quality management systems, with permission from the respective heads. To avoid bias, the same time window of 12 to 18 months after the start of the project was used for all firms. Survey responses on enablers and barriers were collected on a five-point Likert scale ranging from "strongly disagree" to "strongly agree".

Analysis was carried out using SPSS version 28 for descriptive and inferential statistics, and Minitab 21 for process capability and control charts. The Python statsmodels and scikit-learn libraries were used for regression and predictive modelling. Before running regression, multicollinearity was checked using the Variance Inflation Factor (VIF), and values above 5

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were treated as problematic. Model fit was checked using R-squared, adjusted R-squared, and the F-statistic given by:

$$F = \frac{(SS_{regression}/k)}{(SS_{residual}/(n-k-1))}$$

where SS_{regression} is the sum of squares due to regression, SS_{residual} is the residual sum of squares, k is the number of predictors, and n is the sample size [19].

For sector-wise comparison, one-way ANOVA was applied, followed by Tukey's post-hoc test where significant differences were found. Predictive accuracy of the regression model was further validated using k-fold cross-validation with k=5, to make sure the results were not specific to one split of the data [20]. Ethical clearance was obtained from the institutional review board, and all firm-level data was anonymised before reporting.

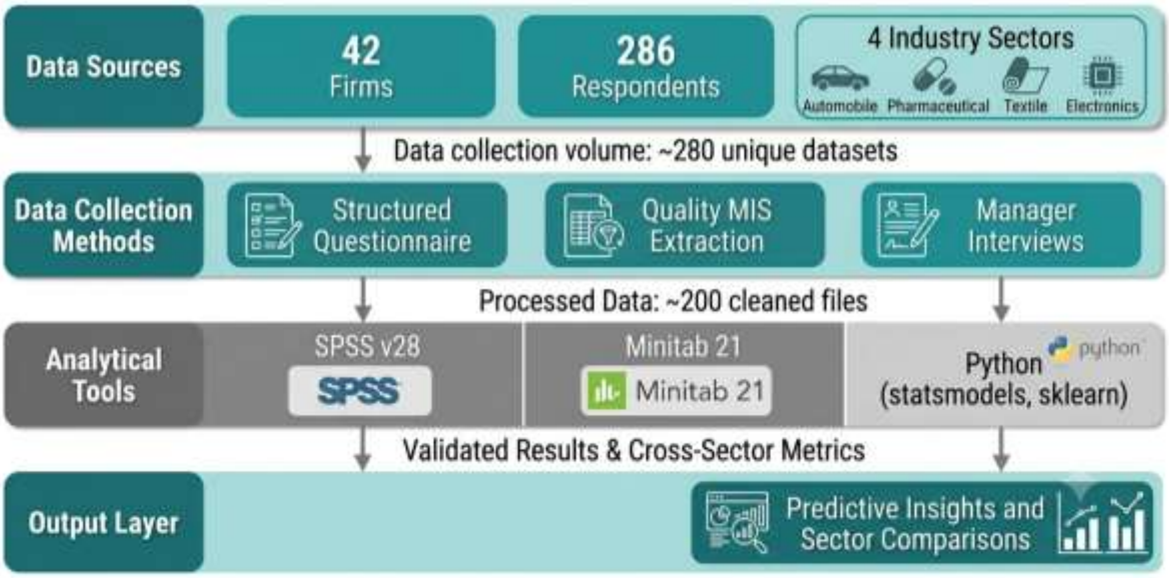

Figure 2: Multi-Layer Experimental Workflow for Lean Six Sigma Evaluation

5. RESULTS

The reliability test gave a Cronbach's alpha of 0.86, indicating strong internal consistency of the survey items. The demographic profile of respondents showed that 72% were male and 28% were female, with the largest functional group being quality engineers (38%), followed by production managers (29%), shop floor supervisors (22%), and senior managers or plant heads (11%).

Table 1: Sector-Wise Distribution of Firms and Respondents

Sector	Number of Firms	Respondents	% of Sample
Automobile	14	92	32.2%
Pharmaceutical	10	68	23.8%
Textile	9	63	22.0%
Electronics	9	63	22.0%
Total	**42**	**286**	**100%**

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The before-and-after analysis of KPIs gave clear evidence of improvement across all sectors, though the size of improvement varied. The automobile sector showed the largest gains, which makes sense given its longer history with Lean Six Sigma and its tighter quality requirements from global OEMs.

Table 2: KPI Improvements Before and After Lean Six Sigma Implementation

KPI	Before (Avg)	After (Avg)	Improvement %
Defect Rate (PPM)	8,420	5,210	38.1%
Cycle Time (min/unit)	14.6	10.7	26.7%
First-Pass Yield (%)	78.4	91.2	16.3%
OEE (%)	64.8	79.5	22.7%
Process Capability (Cpk)	0.91	1.42	56.0%

The multiple regression analysis on implementation success gave an adjusted R-squared of 0.79, meaning that about 79% of the variation in success scores could be explained by the chosen predictors. Leadership support came out as the strongest predictor, followed by training quality and employee involvement. The use of digital tools was significant but had a smaller coefficient, suggesting that technology helps but cannot replace the basics of leadership and people engagement.

Table 3: Multiple Regression Results for Implementation Success

Predictor	Coefficient (β)	Std. Error	t-value	p-value
Leadership Support	0.412	0.058	7.10	0.000***
Training Quality	0.328	0.063	5.21	0.000***
Employee Involvement	0.276	0.061	4.52	0.000***
Digital Tool Usage	0.184	0.072	2.56	0.011*
Project Selection Quality	0.241	0.069	3.49	0.001***
Constant	1.082	0.214	5.06	0.000***

*Note: Significance levels — *p<0.05, **p<0.01, **$p<0.001$. Adjusted $R^2 = 0.79$; $F = 84.2$, $p < 0.001$.

The classification version of the model, where firms were tagged as "successful" or "partially successful", gave an accuracy of 84% on the validation sample, with a sensitivity of 0.82 and specificity of 0.85.

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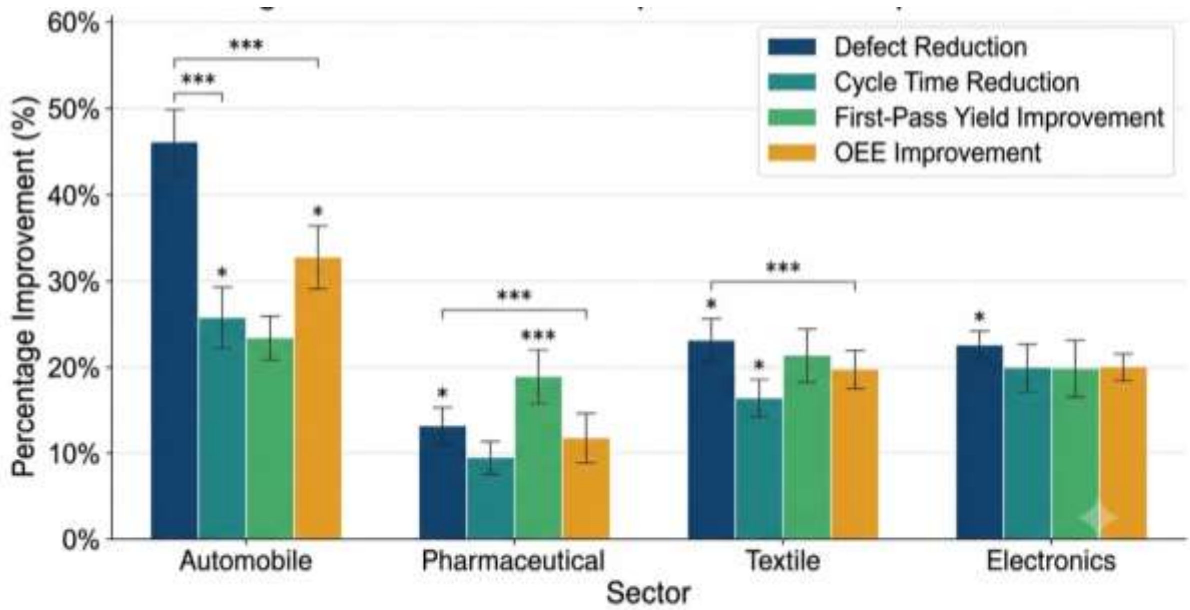

Figure 3: Sector-Wise Comparison of KPI Improvements

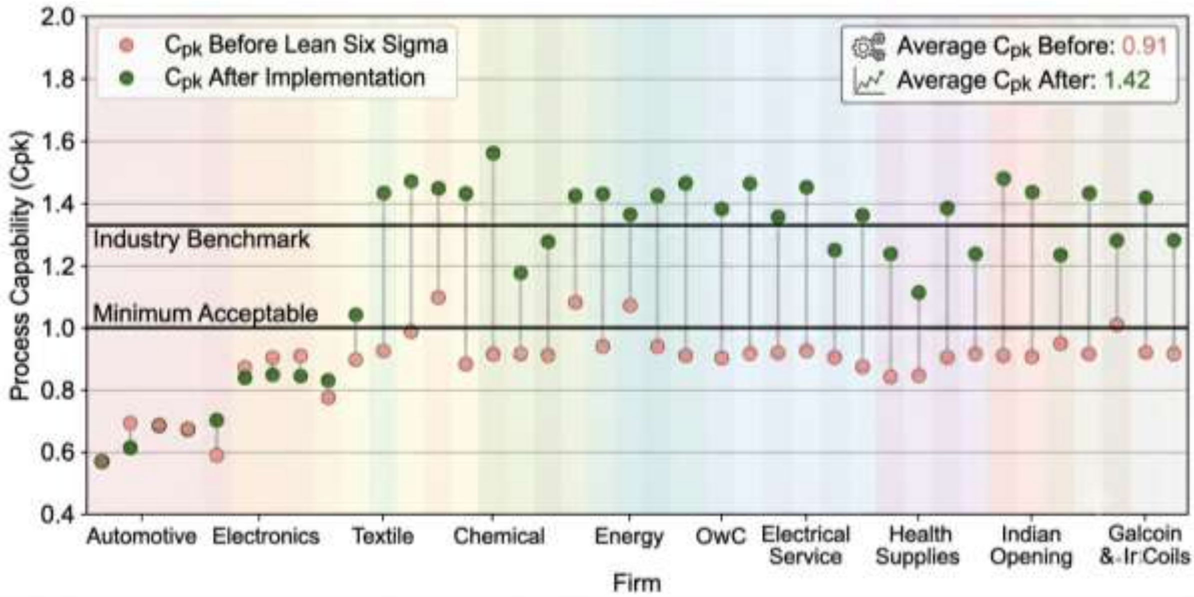

Figure 4: Process Capability (Cpk) Improvement Across Firms

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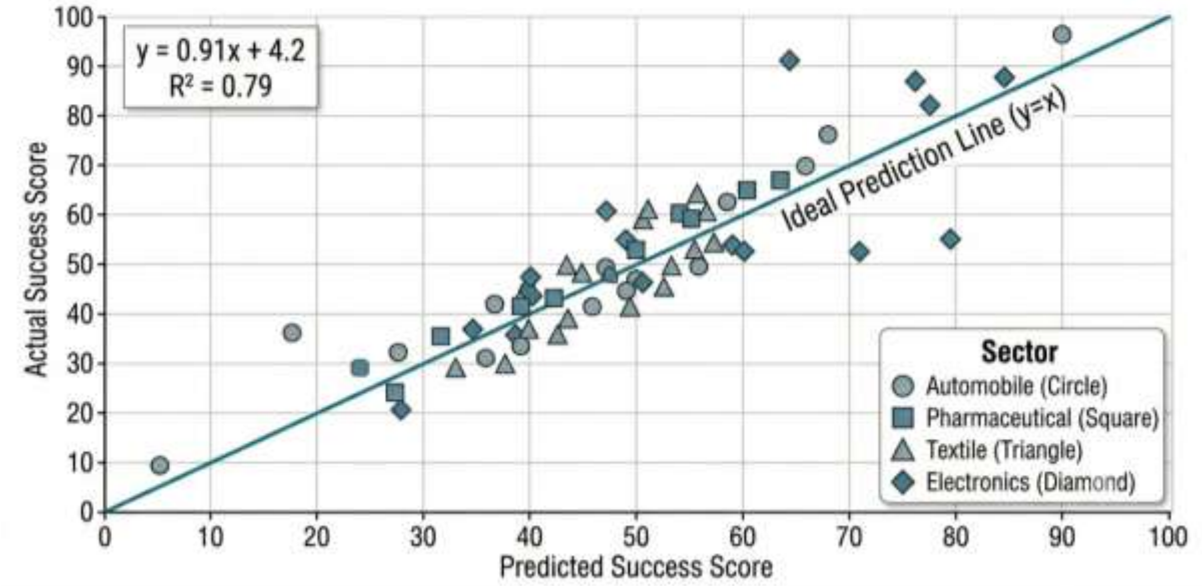

Figure 5: Predicted vs Actual Success Scores of Firms

When sector-wise differences were tested using ANOVA, the F-value came out to 6.42 with a p-value below 0.001, meaning the differences between sectors were statistically significant. Tukey's post-hoc test confirmed that the automobile sector outperformed textile and electronics in defect reduction, while pharmaceutical led in first-pass yield improvement.

6. DISCUSSION

The results of this study tell a fairly encouraging story, but also one with some important caveats. On the surface, the numbers look good. A 38% drop in defect rates and a 27% cut in cycle time are not small improvements, especially when achieved within 12 to 18 months. These results suggest that Lean Six Sigma, when properly applied, does deliver real value in Indian manufacturing. The improvement in process capability from an average Cpk of 0.91 to 1.42 is particularly important, because Cpk above 1.33 is generally considered the mark of a process that is genuinely in control and capable of meeting customer specifications consistently.

However, when one looks beneath the average numbers, the picture becomes more interesting. The regression model clearly shows that the technical tools of Lean Six Sigma are only part of the story. Leadership support and training quality together explained a larger share of success than any other group of factors. This finding lines up with what many Indian managers have said in informal discussions over the years, that Lean Six Sigma is more of a management philosophy than a set of statistical techniques. When the plant head genuinely believes in the approach and walks the talk, projects tend to succeed. When the plant head treats it as a tick-box exercise to please customers, projects either fail outright or fade away after the initial fanfare.

The sector-wise differences also deserve some thought. The automobile sector did the best, which is no surprise given that global OEMs have been pushing their Indian suppliers towards Six Sigma standards for over two decades. Pharmaceutical firms also performed well, partly because of strict regulatory requirements from agencies like the FDA, which create a built-in pressure to maintain process discipline. Textile and electronics firms showed real

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improvements too, but the gains were smaller, possibly because these sectors have shorter product cycles and more variability in raw materials, which makes process control harder.

The role of digital tools came out as significant but secondary. This is a useful corrective to the current trend where every problem is expected to be solved by adding more sensors or more dashboards. The data suggests that digital tools amplify the gains from Lean Six Sigma, but they do not create those gains on their own. A factory with weak leadership and poor training will not be saved by an expensive IoT setup. On the other hand, a factory with strong fundamentals can use digital tools to move faster and measure more accurately.

One limitation worth mentioning is that the sample was drawn from medium and large firms. Small enterprises, which form the majority of Indian manufacturing, were left out because most of them do not have formal Lean Six Sigma programmes. Future research could look specifically at simplified versions of the methodology that might work for small firms, perhaps using lighter tools and shorter project cycles. Another limitation is that the study captured outcomes at 12 to 18 months. Long-term sustainability, say at 36 or 48 months, may show a different pattern, and longitudinal studies would help fill this gap.

7. CONCLUSION

This study set out to examine how Lean Six Sigma is actually working in the Indian manufacturing sector, and the findings give a clear picture. When implemented seriously, with proper leadership backing and good training, Lean Six Sigma delivers measurable improvements across defect rates, cycle time, first-pass yield, and overall equipment effectiveness. The 42 firms in this study, spread across four important sectors, collectively showed gains that translate into real cost savings and quality improvements. The predictive model built in this paper, with an accuracy of around 84% and an adjusted R-squared of 0.79, also shows that success in Lean Six Sigma is not random. It is largely driven by a small set of human and organisational factors that companies can actively manage.

The main contribution of this paper lies in offering a multi-sector, evidence-based view of Lean Six Sigma in India, going beyond single-company case studies. For practitioners, the takeaway is that buying expensive tools or hiring outside consultants is not the secret. The real work happens in winning the trust of middle managers, training the workforce properly, and choosing projects that match business priorities. Companies that get these basics right tend to succeed, regardless of which sector they operate in.

For policymakers and industry bodies, the findings suggest that programmes to encourage Lean Six Sigma adoption among smaller firms could have significant economy-wide benefits. Subsidised training programmes, shared expert pools, and simplified toolkits could help bring smaller manufacturers into the fold. With the manufacturing sector being central to India's growth ambitions, even small percentage improvements in defect rates and cycle times, when scaled across thousands of firms, could mean billions of rupees in productivity gains.

Looking ahead, the next frontier seems to be the blending of Lean Six Sigma with digital technologies like IoT, AI-based defect detection, and predictive maintenance. Early evidence from this study suggests that digital tools work best when layered on top of a strong Lean Six Sigma foundation, not as a replacement for it. Future research should explore this hybrid model in more depth, particularly looking at how data-driven decision-making can speed up the Analyse and Control phases without losing the discipline that makes Lean Six Sigma effective

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in the first place. India's manufacturing sector has come a long way, and with the right mix of methodology, leadership, and technology, the next phase of growth looks promising.

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