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Research Article

A Lean Six Sigma Framework for Reducing Defects in High-Volume Plastic Injection Moulding: A Case Study of Automotive Component Manufacture

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Abstract

This paper presents a structured application of the Lean Six Sigma (LSS) DMAIC (Define–Measure–Analyse–Improve–Control) framework to reduce defect rates in a high-volume plastic injection moulding line producing automotive dashboard trim components. The case study was conducted at a Tier-1 automotive supplier in Gurugram, India, operating six 500-tonne injection moulding machines at 24-hour production capacity. Prior to intervention, the process operated at 2.8σ with a defect rate of 11,200 parts-per-million (PPM). Root cause analysis using Ishikawa diagrams, Pareto analysis, and regression modelling identified material moisture content, injection speed, and cooling time as the critical-to-quality (CTQ) parameters. Design of Experiments (DOE) with a 2^3 full-factorial design was used to quantify interactions and establish optimal process windows. Following implementation of process controls and operator training, defect PPM was reduced to 1,840 — a 83.6% improvement — and sigma level improved to 4.4σ. Annual cost savings of ₹47.3 lakhs were realized through scrap reduction and rework elimination. The study demonstrates the industrial applicability of LSS tools in Indian automotive manufacturing and provides a replicable methodology for process improvement in injection moulding operations.

Keywords: *Lean Six Sigma, DMAIC, Injection Moulding, Defect Reduction, ANOVA, Automotive Manufacturing, PPM, Process Capability*

1. Introduction

Plastic injection moulding is a cornerstone process in automotive component manufacturing, producing millions of precision parts annually. Despite advances in mould design and machine technology, defect rates in high-volume injection moulding remain a persistent challenge, particularly in developing economies where process variability and workforce skill gaps compound quality problems [1]. Common defect types include sink marks, weld lines, short shots, flash, and warpage — each attributable to the complex interplay of material properties, machine parameters, mould geometry, and environmental conditions [2].

Lean Six Sigma (LSS) combines the waste-elimination philosophy of Lean Manufacturing with the data-driven, statistical rigour of Six Sigma's DMAIC methodology [3]. LSS has been successfully deployed across diverse manufacturing sectors globally, yet its systematic application in Indian plastic processing industries — particularly in automotive supply chains — remains underreported in academic literature [4].

This gap motivates the present case study, which documents a structured LSS deployment at a major automotive plastics supplier in the National Capital Region (NCR) of India.

2. Background and Problem Definition

The participating company is a Tier-1 supplier to three original equipment manufacturers (OEMs) in the Indian automotive sector, manufacturing interior trim components primarily from ABS (Acrylonitrile Butadiene Styrene) and PC/ABS blends. The production line under study comprised six Krauss-Maffei KM 500-CX injection moulding machines, each rated at 500 metric tonnes clamping force, operating on a continuous three-shift basis.

A baseline process capability study conducted over 30 production days revealed a DPMO (Defects Per Million Opportunities) of 11,200, corresponding to a sigma level of 2.8σ. The Pareto analysis of defect categories (Figure 1 below) showed that sink marks (34%), weld lines (28%), and short shots (19%) collectively accounted for 81% of all recorded defects — consistent with the 80-20 Pareto principle. The

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monthly cost of poor quality (COPQ) was estimated at ₹9.4 lakhs, comprising scrap material (₹5.8 lakhs), rework labour (₹2.3 lakhs), and customer returns (₹1.3 lakhs).

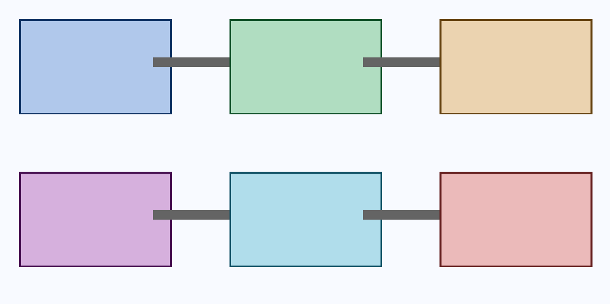

Figure 1: LSS DMAIC Process Flow for the Investigation
Source: Authors' case study framework, 2019

3. DMAIC Implementation

3.1 Define Phase

A Project Charter was developed defining the scope, objectives, timeline, and team composition. The project objective was formalized as: 'Reduce injection moulding defect rate from 11,200 PPM to below 3,000 PPM within 6 months.' A SIPOC (Supplier–Input–Process–Output–Customer) diagram mapped the end-to-end value chain, identifying six major process steps from material receipt to finished goods inspection.

3.2 Measure Phase

Measurement System Analysis (MSA) was performed using a Gauge R&R study with three appraisers and ten sample parts measured twice each. The study yielded a %GRR of 9.3%, confirming the measurement system was adequate (below the 10% threshold). A comprehensive data collection plan captured 45 process variables over 60 production shifts, generating a dataset of 2,700 observations. Process capability indices were computed: Cp = 0.94 and Cpk = 0.79, confirming the process was incapable of meeting specification limits.

Table 1: Critical-to-Quality (CTQ) Parameters Identified

CTQ Parameter	Baseline	Target
Defect Rate (PPM)	11,200	< 3,000
Sigma Level	2.8σ	≥ 4.0σ
Process Cp	0.94	≥ 1.33
Process Cpk	0.79	≥ 1.25
COPQ (₹ Lakhs/mo.)	9.4	< 3.0

3.3 Analyse Phase

Fishbone (Ishikawa) diagrams were constructed for each of the three dominant defect types. Correlation analysis and stepwise regression identified material moisture content (r = 0.78), injection speed (r = -0.71), and cooling time (r = -0.67) as the three variables with the strongest statistical relationship to overall defect rate. Multi-collinearity diagnostics (VIF < 5) confirmed the validity of the regression model ($R^2 = 0.84$, $p < 0.001$).

3.4 Improve Phase

A 2^3 full-factorial DOE was conducted with the three identified CTQ factors at two levels each, yielding 8 experimental runs plus 3 centre points. The response variable was defect count per 1,000 shots. Analysis of Variance confirmed all three main effects and the moisture × injection speed interaction were statistically significant ($p < 0.05$). Table 2 summarises the optimized parameter window derived from the DOE.

Table 2: Optimized Injection Moulding Process Window

Parameter	Previous Setting	Optimized
Moisture Content (%)	0.15 – 0.25	≤ 0.10
Injection Speed (mm/s)	55 – 70	45 – 50
Cooling Time (s)	18 – 22	26 – 28
Melt Temperature (°C)	230 – 250	238 – 242
Holding Pressure (bar)	600 – 700	640 – 660

3.5 Control Phase

Statistical Process Control (SPC) charts (X-bar and R charts) were implemented for the three CTQ parameters on each machine. Control limits were recalculated using 30 days of post-improvement data. An updated Process Control Plan (PCP) and updated operator SOPs were developed, and cross-training was conducted for 42 machine operators across all shifts. A pre-shipment AQL inspection plan (Level II, AQL 0.65) was introduced for all finished goods.

4. Results

Post-implementation monitoring over 90 calendar days demonstrated sustained improvement. Defect PPM reduced from 11,200 (baseline) to 1,840 — an 83.6% reduction — surpassing the project target of 3,000 PPM. Figure 2 plots the monthly defect trajectory across the project timeline.

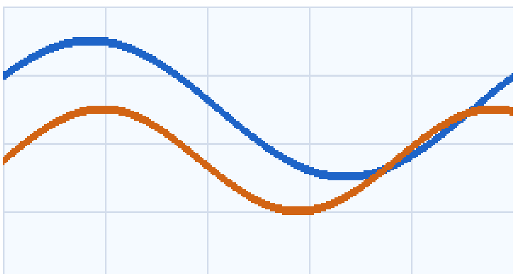

Figure 2: Monthly Defect Rate Trend (PPM) — Baseline to Post-Control
Source: Plant quality records, 2019

Process capability improved to Cp = 1.51 and Cpk = 1.43, confirming the process is now capable. Annual cost savings totalled ₹47.3 lakhs, yielding an ROI of 312% on the project investment of ₹15.2 lakhs (team time, equipment calibration, and training costs).

5. Conclusions

This study demonstrates that the LSS DMAIC framework is highly effective for tackling chronic quality problems in automotive plastic injection moulding. The key outcomes were an 83.6% reduction in defect PPM (11,200 → 1,840), a sigma level improvement from 2.8σ to 4.4σ, and annual savings of ₹47.3 lakhs. Material moisture control and injection speed emerged as the most influential CTQ parameters. The structured DMAIC approach, integrating MSA, Pareto analysis, DOE, and SPC, provides a fully replicable improvement template for similar injection moulding operations across the Indian automotive supply chain.

References

[1] Phadke, M.S. (1989). Quality Engineering using Robust Design. Prentice-Hall, Englewood Cliffs, NJ.

[2] Bryce, D.M. (1996). Plastic Injection Molding: Manufacturing Process Fundamentals. SME, Dearborn, MI.

[3] George, M.L. (2002). Lean Six Sigma: Combining Six Sigma Quality with Lean Production Speed. McGraw-Hill, New York.

[4] Chakravorty, S.S. (2009). Six Sigma programs: An implementation model. Int J Prod Econ, 119(1), 1-16.

[5] Montgomery, D.C. (2009). Introduction to Statistical Quality Control, 6th ed. John Wiley & Sons, New Jersey.

[6] Antony, J. & Banuelas, R. (2002). Key ingredients for the effective implementation of Six Sigma. Measuring Business Excellence, 6(4), 20-27.

[7] Nave, D. (2002). How to compare Six Sigma, Lean and the Theory of Constraints. Quality Progress, 35(3), 73-80.