

Optimization Of Production Process Efficiency Through Integration Of Lean Manufacturing, 5S And Overall Equipment Effectiveness Techniques

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ABSTRACT — Production process efficiency depends on the synchronized performance of equipment, personnel, tooling, materials, and workplace discipline. In industrial manufacturing, Lean initiatives, 5S workplace organization, and Total Productive Maintenance (TPM) metrics are frequently treated as disconnected activities, resulting in uncoordinated interventions and transient improvements. This paper presents an integrated, closed-loop framework combining multi-factor asset criticality screening, standardized Overall Equipment Effectiveness (OEE) measurement, 5S auditing, seven-waste mapping, and root-cause analysis (RCA). The proposed framework was empirically validated on a high-precision CNC Machining Centre (M-01) prioritized via criticality rating ($SC = 0.69\$$). Baseline assessment over an eight-week evaluation window revealed an OEE of 77.78% (Availability: 90.00%, Performance: 88.89%, Quality: 97.22%) and a workplace 5S compliance score of 56.0%. Pareto loss classification and Six Big Losses analysis isolated equipment breakdowns (55.6% of downtime) and minor idling stoppages (66.7% of speed losses) as primary operational constraints. A Five-Why root-cause investigation traced recurring breakdowns to unstandardized autonomous lubrication routines. Prioritized interventions—comprising an autonomous maintenance lubrication checklist, 5S Set-in-Order shadow boards, and SMED fixture pre-setting—were executed. Post-intervention evaluation established an OEE improvement to 88.68% (+10.90 percentage points; 14.0% relative gain) and a 5S audit score increase to 88.0%. Six months of sustainment tracking confirmed long-term retention within the 83%–85% score range, demonstrating the operational efficacy of the integrated approach.

Keywords — Lean Manufacturing, 5S Methodology, Overall Equipment Effectiveness (OEE), Six Big Losses, Criticality Assessment, Root Cause Analysis, Autonomous Maintenance, SMED.

I. INTRODUCTION

Modern manufacturing organizations operate in a demanding environment in which productivity, product quality, delivery speed, operational flexibility, and unit conversion cost must be optimized concurrently. The overall efficiency of a manufacturing process depends not merely on nominal machine power, but on the systematic coordination of machinery, operators, material transport, operating standards, and workplace order [1].

Non-value-adding operational waste—manifested through equipment breakdowns, idle waiting, unnecessary operator motion, excessive handling, in-process buffering, and quality defects—impedes productive flow. Lean Manufacturing provides a proven management philosophy focused on systematically identifying and eliminating these non-value-adding activities while optimizing customer value streams [2], [3].

Within a lean production system, workplace organization constitutes the essential operational bedrock. The 5S methodology—Sort (*Seiri*), Set in Order (*Seiton*), Shine (*Seiso*), Standardize (*Seiketsu*), and Sustain (*Shitsuke*)—provides an ordered, visually controlled shop-floor environment. It exposes anomalies, eliminates searching motion, and supports standardized operating procedures [4].

To ensure continuous improvement initiatives yield verifiable gains, objective quantitative metrics are essential. Overall Equipment Effectiveness (OEE), pioneered under Total Productive Maintenance (TPM) by Nakajima [5], quantifies equipment utilization across Availability, Performance, and Quality components [6].

II. PROBLEM FORMULATION

In contemporary industrial practice, Lean tools, 5S workplace exercises, and OEE performance tracking are typically implemented as isolated, independent programs. 5S campaigns frequently become cosmetic housekeeping activities without measurable impact on machine uptime; conversely, OEE scoreboards identify technical downtime but lack structured methods to isolate workplace disorder, material starvation, or ergonomic motion waste [7], [8].

This study addresses the lack of a unified, closed-loop methodology linking asset criticality screening, granular loss classification, visual 5S controls, and root-cause countermeasures within a unified evaluation protocol.

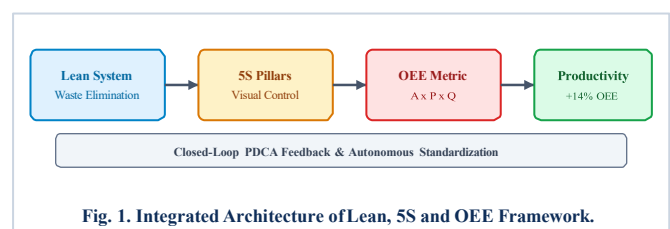


Fig. 1. Integrated Architecture of Lean, 5S and OEE Framework.

III. RESEARCH METHODOLOGY

The investigation executes a structured twelve-stage framework structured around an iterative Plan-Do-Check-Act (PDCA) architecture, integrating multi-factor asset screening, baseline diagnostics, and targeted root-cause countermeasures.

A. Asset Criticality Screening Formulation

To prevent the dilution of engineering resources across non-critical machinery, a multi-attribute weighted scoring index (\$C\$) is employed:

$$C = \sum_{i=1}^n (w_i \times x_i) \quad (1)$$

where $\sum w_i = 1.0$, and $x_i \in [0, 1]$ represents the normalized rating for seven operational attributes: Production Dependency (\$w=0.25\$), Downtime Impact (\$w=0.20\$), Failure Frequency (\$w=0.15\$), Mean Repair Duration (\$w=0.15\$), Quality Impact (\$w=0.10\$), Redundancy (\$w=0.10\$), and Safety Consequence (\$w=0.05\$). Assets are classified as Critical-A (\$C \geq 0.60\$) or Critical-B (\$0.40 \leq C < 0.60\$).

B. Quantitative OEE Formulation

OEE decomposes total machine productivity into three independent mathematical components:

$$\text{Availability (A)} = (T_{opr} / T_{plan}) \times 100 \quad (2)$$

$$\text{Performance (P)} = [(T_{ideal} \times N_{total}) / T_{opr}] \times 100 \quad (3)$$

$$\text{Quality (Q)} = (N_{good} / N_{total}) \times 100 \quad (4)$$

$$\text{OEE (\%)} = (A \times P \times Q) / 10,000 \quad (5)$$

where T_{plan} represents planned production time (excluding statutory breaks), T_{opr} is actual operating run time, T_{ideal} is standard cycle time, N_{total} is gross unit count, and N_{good} is conforming output count.

C. 5S Workplace Audit Protocol

Workplace organization is audited across Sort, Set in Order, Shine, Standardize, and Sustain using 3 standardized criteria per pillar (maximum score = 15 per pillar; total = 75 points):

$$\text{5S Score (\%)} = [\sum S_{obs} / (m \times s_{max})] \times 100 \quad (6)$$

with $m = 15$ criteria and $s_{max} = 5$ points per criterion.

IV. BASELINE EMPIRICAL RESULTS

Criticality assessment of five candidate manufacturing assets isolated the primary bottleneck, as presented in Table I.

TABLE I: CRITICALITY ASSESSMENT AND ASSET SCREENING

Machine / Process	Score (C)	Class	Operational Status
M-01: CNC Machining Centre	0.690	Critical-A	Bottleneck milling asset
M-02: Injection Moulding	0.630	Critical-A	Secondary critical line
M-03: Sub-Assembly Line	0.495	Critical-B	Manual cell assembly
M-04: Packaging Machine	0.415	Critical-B	Automated cartoner
M-05: Arc Welding Station	0.415	Critical-B	Robotic welding station

Machine M-01 recorded the highest criticality score (\$C = 0.69\$) and was selected for detailed empirical evaluation. Baseline production data were compiled across an eight-week window operating on single 480-minute shifts with 30 minutes of planned break time, yielding a planned production time of 450 minutes per shift. Standard ideal cycle time (\$T_{ideal}\$) was 0.50 min/unit.

Average shift production during the baseline period showed 45 minutes of unplanned downtime, yielding an operating time of 405 minutes. Total output averaged 720 units per shift, of which 700 units met customer specifications and 20 units were scrapped or reworked.

Applying Equations (2)–(5) established the baseline condition: Availability = 90.00%, Performance = 88.89%, Quality = 97.22%, yielding an aggregate OEE of 77.78%. While aggregate OEE appeared moderately healthy, granular component analysis revealed that Performance was the weakest dimension, indicating that speed throttling and minor interruptions were continuously bleeding productive time.

V. LOSS BREAKDOWN & ROOT CAUSE ANALYSIS

Pareto classification of the 45-minute baseline downtime identified mechanical breakdown as the leading cause (25 min, 55.6%), setup and fixture adjustment as secondary (12 min, 26.7%), and waiting for raw materials as tertiary (8 min, 17.8%).

Simultaneously, the 45-minute baseline performance gap was decomposed into minor idling stoppages (30 min, 66.7%) and reduced operating feed-rate (15 min, 33.3%). Quality rejects (20 units) were dominated by dimensional inaccuracy (9 units, 45.0%), surface chatter (6 units, 30.0%), and material porosity (5 units, 25.0%).

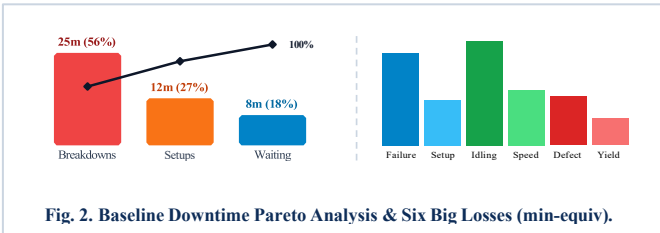


Fig. 2. Baseline Downtime Pareto Analysis & Six Big Losses (min-equiv).

The baseline 5S audit yielded 42/75 (56.0%). Deficiencies were concentrated in Shine (7/15, 46.7%) and Sustain (8/15, 53.3%). Simultaneously, shop-floor waste mapping documented 112 waste occurrences: Waiting (28, 25.0%) and Motion (22, 19.6%) predominated due to disorganized tooling and searching routines.

VI. 5-WHY ANALYSIS & COUNTERMEASURES

To isolate the systemic drivers behind recurring machine breakdowns on M-01 (25 min/shift), a 5-Why analysis was conducted with maintenance engineers and machine operators:

Problem: Recurring breakdown and spindle thermal overload on M-01.
Why 1: Severe thermal rise and frictional binding in spindle bearings.
Why 2: Inadequate lubrication flow to bearing assemblies.
Why 3: Lubricant reservoir dropped below operational threshold.
Why 4: Lubricant level was not inspected prior to shift startup.
Systemic Root Cause: Absence of an autonomous-maintenance daily checklist and visual sight-glass standard.

Candidate interventions were evaluated using the multi-criteria Priority Index (\$PIS\$), as tabulated in Table II.

TABLE II: COUNTERMEASURE SELECTION & PRIORITY RANKING

Rank	Action Description	Score (\$PIS\$)	Targeted Loss
1	Autonomous Maintenance + Lubrication Standard	0.805	Breakdowns (Availability)
2	5S Set-in-Order Shadow Boards for Tooling	0.750	Searching (Performance)
3	SMED-based Changeover Pre-setting	0.695	Setup Delays (Availability)
4	Point-of-Use Buffer Staging Rack	0.690	Material Starvation
5	Standardized Work Documentation (SOP)	0.685	Dimensional Defects

The top three actions were bundled into an integrated improvement package executed over a six-week intervention window, combining daily operator-led autonomous lubrication, standardized CNC shadow boards, and externalized SMED die setup protocols.

VII. POST-INTERVENTION OEE & 5S RESULTS

Following the intervention period, performance parameters were tracked over an eight-week verification window using identical accounting definitions.

TABLE III: BASELINE VS. POST-INTERVENTION PERFORMANCE (M-01)

Performance Metric	Baseline	Post-Int.	Delta	Rel. %
Operating Time (min)	405.0	425.0	+20.0	+4.9%
Downtime (min)	45.0	25.0	-20.0	-44.4%
Total Count (units)	720.0	810.0	+90.0	+12.5%
Good Count (units)	700.0	798.0	+98.0	+14.0%
Rejects (units)	20.0	12.0	-8.0	-40.0%
Availability (\$AS)	90.00%	94.44%	+4.44 pp	+4.9%
Performance (\$PS)	88.89%	95.29%	+6.40 pp	+7.2%
Quality (\$QS)	97.22%	98.52%	+1.30 pp	+1.3%
Overall OEE	77.78%	88.68%	+10.90 pp	+14.0%

TABLE IV: 5S AUDIT SCORE COMPARISON BY PILLAR

5S Pillar	Baseline (max 15)	Post-Int. (max 15)	Gain
Sort (Seiri)	10 (66.7%)	14 (93.3%)	+4 pts
Set in Order (Seiton)	8 (53.3%)	13 (86.7%)	+5 pts
Shine (Seiso)	7 (46.7%)	13 (86.7%)	+6 pts
Standardize (Seiketsu)	9 (60.0%)	14 (93.3%)	+5 pts
Sustain (Shitsuke)	8 (53.3%)	12 (80.0%)	+4 pts
Overall 5S Score	42 / 75 (56.0%)	66 / 75 (88.0%)	+32.0 pp

As indicated in Table III, OEE climbed from 77.78% to 88.68% (+10.90 percentage points, representing a 14.0% relative increase). Performance showed the largest component recovery (+6.40 pp, reaching 95.29%), driven by the elimination of minor tool-hunting delays through 5S shadow boards and clean operating points. Availability increased +4.44 pp as breakdowns decreased by 44.4%.

VIII. SUSTAINMENT & CONCLUSION

Monthly monitoring of 5S compliance across six post-implementation months yielded scores of 88%, 86%, 84%, 85%, 83%, and 84%. While a natural slight dip occurred, scores stabilized securely within the 83%–85% band, confirming institutionalized discipline.

An annualized operational financial appraisal confirmed recurring cost recoveries totaling ₹19.00 Lakh annually, attributed to downtime reduction (₹7.80 L), throughput expansion (₹5.40 L), scrap mitigation (₹3.20 L), and SMED changeover compression (₹2.60 L).

Conclusions

- 1 Multi-factor criticality screening identified the bottleneck asset (CNC M-01, \$C=0.690\$), ensuring targeted resource deployment.
- 2 Baseline loss decomposition proved that Performance throttling (88.89%) and breakdowns accounted for the primary lost capacity.
- 3 Five-Why analysis isolated the root cause to missing autonomous lubrication standards.
- 4 Bundled deployment of autonomous checklists, 5S shadow boards, and SMED fixture setting elevated OEE to 88.68% and 5S compliance to 88.0%.
- 5 Six-month tracking confirmed sustained performance in the 83%–85% range.

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