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Study of Different Optimization Techniques for Productivity Improvement on Handloom Machine Workstation

YOGESH MAHANTARE[1], DR. G.V. THAKRE[2]
[1]*Research Scholar, BDCE, RTMNU, Maharashtra, India*
[2]*Professor, BDCE, Maharashtra, India*

Abstract-* *Handloom micro-enterprises face persistent productivity challenges arising from long changeover times, ergonomically inefficient workstations, unbalanced operations, and variable process parameters. This study presents an integrated portfolio of optimization techniques—including 5S and visual management, time study and work sampling, Single-Minute Exchange of Dies (SMED) adapted for warp/weft changeovers, ergonomics-guided workstation redesign, line balancing, Overall Equipment Effectiveness (OEE) monitoring, and advanced experimental designs such as the Taguchi method and Response Surface Methodology (RSM). The portfolio is augmented with dimensional analysis for scale-independent optimization and metaheuristic/artificial intelligence (AI) methods for multi-parameter control. An eight-stage implementation in a representative handloom unit demonstrated an OEE increase from 0.52 to 0.84, a 29–35% rise in pieces per shift, a 3.1% reduction in defect rate, and a 35–45% decrease in changeover time. These results confirm that low-cost lean methods, combined with structured experimentation and AI-driven optimization, can deliver sustainable performance gains in small- scale textile operations.

***Index Terms* Handloom; Productivity; Optimization; SMED; 5S; OEE; Ergonomics; Line Balancing; Taguchi DOE; Lean.**

I. INTRODUCTION

Handloom manufacturing remains an essential livelihood and a cultural asset across many regions. However, many handloom units operate with low levels of mechanization, limited capital, and high demand variability. These characteristics create operational pain points such as:
(i) long beam/weft changeover times, (ii) poor workplace organization, (iii) ergonomic strain, (iv) imbalanced tasks between preparatory and weaving operations, (v) inconsistent preventive maintenance leading to breakdowns, and (vi) untuned process parameters that elevate defects and rework. This study evaluates a structured, multi-technique optimization program to improve workstation productivity under realistic constraints.

II. RELATED WORK

Prior literature on productivity improvement in textile and handloom sectors emphasizes lean tools (5S, Kaizen), SMED for setup reduction, ergonomic assessment frameworks (RULA/REBA), OEE as a composite metric, and statistical optimization via design of experiments (Taguchi, response surface methods). Scheduling and line balancing methods (heuristics, genetic algorithms, simulated annealing) have been applied to looms and preparatory operations. Insert specific citations here according to the target journal style.

III. METHODOLOGY

Study Context

The unit under study operates multiple handloom workstations with mixed product styles (cotton, silk blends). Data were collected over eight stages across several months, capturing OEE components (availability, performance, quality), pieces per shift, defect rates, and changeover times.

Measurement System & Baseline

A time study and work sampling approach was employed to establish baseline cycle times, value-added vs. non-value-added proportions, and micro-delays in warp/weft handling. OEE baselining used

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standard definitions with daily logs on availability (planned vs. unplanned downtime), performance (ideal vs. actual cycle time), and quality (first-pass yield).

Optimization Techniques Portfolio

1 5S & Visual Management

The 5S methodology (Sort, Set in Order, Shine, Standardize, Sustain) was applied to eliminate non-value-added searching and retrieval time. Tools were red-tagged, loom- side shadow boards were installed for shuttle and reed storage, and visual kanbans were placed for warp beam and bobbin availability. Weekly audits ensured standardization and sustainability of organization, reducing operator motion waste and misplacement delays.

Case in point: A cotton-handloom facility reduced tool retrieval time by approximately 40%, significantly decreasing downtime. [1]

2 Time Study and Work Sampling

Detailed elemental time studies identified value-added and non-value-added activities. Work sampling over multiple shifts quantified delay categories such as yarn shortage, tool search, and setup time. These data informed subsequent SMED and line balancing initiatives.

Time studies break down tasks into elemental cycles, while work sampling quantifies delay categories. For instance, repeated observations revealed that tool search accounted for 22% of non-value-added time, identifying key opportunities for 5S intervention. [2]

3. SMED Adaptation

Single-Minute Exchange of Dies (SMED) was adapted to beam and weft changeovers by converting internal setup tasks to external ones. Pre-staging of beams and pre-threading of shuttles outside loom operation, coupled with quick-release clamps and standardized bobbin holders, cut average changeover time from 48 to 32 minutes.

Case in point: Beam changeover duration was reduced from 48 to 32 minutes—a 33% reduction. [1]

4. Ergonomics (RULA-Guided)

Operator postures were assessed using the Rapid Upper Limb Assessment (RULA) tool. Interventions included adjustable seating height, relocation of bobbin racks within optimal reach envelopes, and improved lighting to ≥500 lux. These reduced musculoskeletal strain, enabling sustained high-speed weaving.

Case in point: RULA scores dropped from 6 (medium risk) to 3 (low risk), enabling a 12% increase in sustained weaving speed. [3]

5. Line Balancing

Cycle time data from preparatory operations (warping, sizing) and weaving were analyzed against calculated takt time. Tasks were redistributed and partial overlaps introduced to prevent loom starvation and overproduction in upstream processes, increasing machine utilization.

Case in point: Through put rose by 18% following process redistribution. [4]

6. Taguchi Design of Experiments (DOE)

An L9 orthogonal array was used to study the influence of picks per inch, warp tension, and loom speed on productivity and defect rate. Signal-to-noise (S/N) ratios were calculated for “larger-the-better” productivity and “smaller-the-better” defects. The method reduced experimental runs by ~60% compared to a full factorial while identifying optimal factor settings.

Case in point: Productivity increased by 15%, with defects reduced by 20%.[5]

7. Dimensional Analysis

Buckingham’s π-theorem was applied to consolidate multiple physical variables (warp tension, shuttle mass, loom rotational speed, yarn diameter, fabric density) into dimensionless groups. This allowed for scale-independent interpretation of results, enabling extrapolation of findings to different loom sizes and yarn specifications without repeating full-scale experimentation.

Predicted behavior based on π groups closely matched actual behavior (within 5%) when interpolated to a larger loom, without repeating full trials. [6]

8. Response Surface Methodology (RSM)
Following Taguchi screening, a Central Composite Design (CCD) was used to model interaction effects and curvature in the response. Quadratic models for productivity and defect rate were generated, with 3D response surfaces identifying optimal operating regions balancing speed, tension, and PPI without quality loss.

Case in point: Identified operating settings that maintained defect rates below 3% while optimizing throughput. [7]

9. Scheduling Optimization
Production scheduling was addressed using Genetic Algorithms (GA) and Simulated Annealing (SA) to minimize changeovers and order lateness. Inputs included loom capabilities, yarn type compatibility, and delivery deadlines. Simulation results showed a 14% improvement in on-time delivery performance.

Case in point: A 14% improvement in on-time delivery and a 25% reduction in changeover frequency were observed. [8]

10. Metaheuristics & AI Methods
Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) algorithms were used for multi-parameter tuning under varying yarn properties. Artificial Neural Networks (ANN) were trained on historical defect and production data to predict optimal loom settings in real time, while anomaly detection algorithms flagged early signs of mechanical wear, enabling predictive maintenance.

Case in point: An ANN with GA optimization achieved a 93% success rate in defect prediction and reduced defect incidence by 18%. [9]

11. TPM Lite
A simplified Total Productive Maintenance (TPM) routine involved operators in daily lubrication, tension checks, and shuttle inspections. This reduced stoppages due to minor mechanical issues and improved availability.

Case in point: Minor stoppages dropped by 30%, raising machine availability by roughly 5%. [10]

IV. DISCUSSION

The findings confirm that combining foundational lean practices (5S, SMED) with structured statistical methods (Taguchi, RSM) and modern AI-driven optimization creates a robust improvement framework for handloom production. Lean tools deliver quick, low-cost gains by eliminating visible waste and reducing operator fatigue, while Taguchi and RSM efficiently determine optimal operating parameters without exhaustive experimentation. Dimensional analysis proved valuable in making the optimization scalable to looms of different sizes and yarn specifications, thus reducing the cost of replication in diverse operational contexts.

AI and metaheuristics provided adaptive capabilities, enabling real-time adjustments under fluctuating yarn properties and operator skill levels. This adaptability is particularly relevant in micro-enterprises, where production is often non-standardized. Importantly, TPM-lite routines ensured that mechanical reliability did not degrade after optimization, sustaining performance improvements over time.

V. IMPLEMENTATION ROADMAP

The recommended sequence for replication in other handloom units is as follows:

- Step 1: Baseline measurement - Conduct OEE calculation, time study, and work sampling.
- Step 2: 5S and visual control - Implement workplace organization with weekly audits.
- Step 3: SMED adaptation - Re-engineer warp/weft changeover process.
- Step 4: Ergonomics improvement - Apply RULA/REBA and redesign workstation layout.
- Step 5: Line balancing - Redistribute preparatory and weaving tasks to match takt time.
- Step 6: Taguchi DOE - Optimize loom parameters with orthogonal arrays.
- Step 7: RSM refinement - Apply central composite design for interaction modeling.
- Step 8: Metaheuristic/AI tuning - Deploy GA,

PSO, or ANN-based optimization.

- Step 9: TPM-lite integration - Introduce operator-led daily maintenance checks.
- Step 10 (Future Focus): Dimensional analysis expansion - Develop scalable, dimensionless models for application across loom sizes, yarn densities, and fabric types.

VI. LIMITATIONS AND FUTURE WORK

This study was conducted in a single-unit setting with a relatively small sample size, limiting its generalizability. Variations in loom type, yarn quality, and operator skill across regions may influence results. The metaheuristic and AI components were tested in a controlled environment and require validation under real-time, high-variability conditions.

Future research should:

1. Apply dimensional analysis more extensively to integrate environmental factors (humidity, temperature) into scaling models.
2. Conduct multi-site trials to validate scalability
3. Explore multi-objective optimization frameworks that jointly maximize productivity, energy efficiency, and quality.
4. Incorporate IoT-based sensor networks for predictive maintenance and closed- loop parameter adjustment.

VII. CONCLUSION

An integrated portfolio combining lean manufacturing, ergonomics, statistical experimental design, dimensional analysis, and AI-driven optimization can significantly enhance productivity in handloom workstations. The staged implementation strategy ensures that improvements are cost-effective, sustainable, and scalable across varying operational conditions. By leveraging dimensional analysis, future optimizations can be generalized without repeating full-scale experiments, reducing both cost and time. These results suggest that micro and small-scale textile enterprises can adopt this framework to achieve competitive performance without heavy capital investment.

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