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Development and Implementation of a Lean Manufacturing Framework for Productivity Improvement in Polytechnic Mechanical Workshop Laboratories

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ABSTRACT: Polytechnic mechanical workshop laboratories constitute the primary environment in which diploma engineering students acquire practical competencies in machining, fitting, welding, and allied manufacturing processes. Despite their central pedagogical importance, these laboratories in many Indian polytechnic institutions continue to operate under traditional, unstructured workshop management practices characterised by poor tool organisation, excessive student idle time, equipment downtime, and inconsistent safety adherence. This paper presents the development and systematic implementation of a Lean Manufacturing framework, adapted from industrial practice, within the mechanical workshop laboratory at P.E.S. Polytechnic, Chhatrapati Sambhajanagar, Maharashtra. The framework integrates the 5S methodology, Value Stream Mapping (VSM), Kaizen-based continuous improvement, visual management, and standardised work instructions to create a structured, productive, and safe learning environment. A phased implementation approach was adopted over two academic semesters, with quantitative performance measurement before and after intervention. Results demonstrate a 71.7% reduction in session setup time, an 82.4% reduction in tool search time, an 85.7% decrease in near-miss safety incidents, and a 25-percentage-point improvement in practical task completion rates. Student satisfaction scores improved from 5.9 to 8.4 on a ten-point scale. The findings affirm that Lean Manufacturing principles, appropriately contextualised for the polytechnic educational setting, offer a replicable and cost-effective model for transforming mechanical workshop productivity and learning outcomes across similar institutions.

KEYWORDS: Lean Manufacturing, 5S Methodology, Value Stream Mapping, Kaizen, Polytechnic Workshop, Productivity Improvement, Visual Management, Standardised Work, Mechanical Engineering Education, Workshop Laboratory Management

I. INTRODUCTION

The polytechnic workshop laboratory occupies a unique and irreplaceable position in the landscape of technical education. Unlike lecture halls or computer laboratories, the mechanical workshop is the space where theory is made tangible, where engineering drawing becomes a turned component, where material science is felt in the resistance of metal against a cutting tool, and where safety culture is either instilled or neglected. For diploma students in mechanical engineering, proficiency developed in the workshop laboratory forms the practical bedrock upon which further education and industrial employment depend.

Yet the typical polytechnic mechanical workshop in India, and in many developing economies, is characterised by challenges that substantially diminish its pedagogical effectiveness. Tools are stored without systematic organisation, obliging students to spend valuable practical time searching rather than performing. Equipment maintenance is reactive rather than preventive, generating unplanned downtime during scheduled laboratory sessions. Safety protocols exist on paper but are inconsistently communicated and enforced. The sequencing of student activities is often poorly planned, creating bottlenecks in which large groups wait for access to a limited number of machines. Faculty and technician time is consumed by crisis management rather than instruction and mentoring. These conditions collectively result in low practical completion rates, safety incidents, and student frustration.

Lean Manufacturing, originating in the Toyota Production System and subsequently formalised into a global management philosophy, offers a rigorous and proven methodology for identifying and eliminating waste from

production processes while improving quality, safety, and throughput. The core tenet of Lean—that every activity in a process should add value and that non-value-adding activities (wastes) should be systematically identified and removed—translates with remarkable directness to the workshop laboratory context. Tool searching is waste. Waiting for an unavailable machine is waste. Reworking a component incorrectly manufactured due to absent standardised instructions is waste. Equipment downtime due to deferred maintenance is waste.

This paper presents a structured account of the design, implementation, and measured outcomes of a Lean Manufacturing framework developed and deployed in the mechanical engineering workshop laboratory at P.E.S. Polytechnic, Nagsenvana, Chhatrapati Sambhajnagar, Maharashtra. The work aims to demonstrate that Lean principles, thoughtfully adapted from an industrial production context to an educational laboratory setting, can produce measurable and significant improvements in productivity, safety, and student learning outcomes, and that the resulting framework is sufficiently replicable to serve as a model for other polytechnic institutions confronting analogous challenges.

II. LITERATURE REVIEW

The body of scholarship examining Lean Manufacturing in educational and laboratory settings has expanded substantially over the past two decades, driven by growing recognition that the principles underpinning industrial lean practice are not inherently context-dependent but reflect universal characteristics of efficient human activity.

Womack, Jones, and Roos (1990) introduced the concept of Lean Thinking to a global audience through their landmark study of the Toyota Production System, identifying five core principles: value definition from the customer perspective, value stream mapping, flow creation, pull-based production, and relentless pursuit of perfection. These principles, while articulated in a manufacturing context, have since been extensively reinterpreted across healthcare, service industries, and education. In the educational context, the "customer" becomes the student, the "value stream" is the sequence of learning activities through which practical competency is developed, and "waste" encompasses all activities that do not contribute to skill acquisition or understanding.

Hirano (1995) provided the foundational framework for 5S as a practical entry point to Lean implementation, demonstrating through numerous industrial case studies that the discipline of Sort, Set in Order, Shine, Standardise, and Sustain creates the visual and organisational preconditions for all subsequent lean improvement activities. Subsequent researchers, including Ho (1999), extended 5S into educational contexts, finding that its principles translate directly to laboratory and classroom environments, where the organisation of learning resources, equipment, and physical space profoundly influences the efficiency and safety of student activity.

Rother and Shook (1999) developed Value Stream Mapping as a structured visualisation tool for identifying waste in production sequences, enabling practitioners to distinguish value-adding from non-value-adding activities and to design improved future-state processes. The application of VSM to laboratory workflow analysis has been demonstrated in medical education settings (Jimmerson, Weber, and Sobek, 2005) and engineering laboratory contexts (Stump et al., 2011), with consistent findings that the mapping process reveals waste categories that are invisible to practitioners operating within the existing system.

Within the Indian polytechnic and vocational education context, Sharma and Singhal (2019) investigated the barriers to workshop productivity improvement, identifying resource constraints, lack of structured management frameworks, and insufficient faculty development as the primary impediments. Mehta and Patel (2020) conducted a pilot implementation of 5S in a polytechnic workshop laboratory in Gujarat, reporting significant improvements in tool retrieval time and student satisfaction, but noting that sustainability required ongoing audit and cultural reinforcement. Kulkarni and Deshpande (2021) extended this work by incorporating standardised work instructions and visual management boards, finding additional improvements in practical task completion rates. The present study builds upon and extends this emerging body of evidence through a more comprehensive framework incorporating VSM, Kaizen cycles, and robust quantitative before-and-after measurement.

III. FRAMEWORK DESIGN AND THEORETICAL BASIS

3.1 Lean Principles Contextualised for the Workshop Laboratory

The Lean Manufacturing framework developed for this study adapts five core industrial Lean principles to the polytechnic mechanical workshop context. Value is defined as any activity that directly develops student practical

competency in machining, fabrication, measurement, or allied skills. Non-value-adding activities (wastes) are classified using an adaptation of the original seven wastes of manufacturing, as described below. The value stream is conceptualised as the sequence of activities from laboratory session commencement through to assessed practical task completion. Flow improvements seek to eliminate waiting, searching, and unproductive movement within the session. The pull principle is adapted to mean that consumables, tools, and equipment are made available at the point of use, triggered by the student's progression through the standardised task sequence rather than through advance batch preparation by the technician. Perfection is pursued through recurring Kaizen cycles involving faculty, technicians, and student feedback.

3.2 Adaptation of the Seven Wastes to the Workshop Context

The seven wastes of manufacturing (Muda), as originally defined by Taiichi Ohno, are reinterpreted for the workshop laboratory context as follows:

- Overproduction: Excessive advance preparation of work-pieces that are subsequently unused in the session.
- Waiting: Student idle time while waiting for machine availability, instructor attention, or tool issue.
- Transportation: Unnecessary movement of tools, materials, or work-pieces across the laboratory due to poor layout.
- Over-processing: Repetitive instructions delivered verbally to each student group due to absence of visual standards.
- Inventory: Excess consumables and unused tools accumulating in the laboratory without organised management.
- Motion: Unnecessary physical movement by students and faculty due to poorly organised workspaces.
- Defects: Incorrectly manufactured components requiring rework, attributable to absent or unclear standardised work instructions.

3.3 Framework Architecture

The Lean framework is structured around five interlocking components, each addressing a specific category of workshop waste and collectively creating a mutually reinforcing system of organised, efficient, and safe laboratory practice. These components are: 5S Workplace Organisation; Value Stream Mapping of Laboratory Workflows; Visual Management Systems; Standardised Work Instructions; and Kaizen-based Continuous Improvement Cycles. The framework is designed for phased implementation over two academic semesters, with each component introduced sequentially to allow assimilation before the next layer is added.

IV. IMPLEMENTATION METHODOLOGY

4.1 Baseline Assessment

Prior to framework implementation, a comprehensive baseline assessment was conducted across all four workshop sections of the P.E.S. Polytechnic mechanical engineering laboratory, encompassing the fitting, machining, welding, and sheet metal shops. The assessment employed direct time-and-motion study to quantify tool search time, session setup duration, equipment downtime, and student waiting time per session. Safety incident records for the preceding three academic years were reviewed and categorised. Student satisfaction was assessed through a validated ten-item questionnaire administered to all second-year diploma students. Laboratory audit scores were established using a structured 100-point audit instrument covering organisation, cleanliness, safety compliance, and documentation completeness.

The baseline assessment revealed an average session setup time of 18.4 minutes, tool search time of 6.8 minutes per student per session, equipment downtime of 4.5 hours per week, and a practical task completion rate of 68%. Near-miss safety incidents averaged 4.2 per semester, and the mean student satisfaction score was 5.9 out of 10. These baseline values established the quantitative benchmarks against which post-implementation measurements would be compared.

4.2 Phase 1 — 5S Implementation (Semester 1, Months 1–3)

The 5S implementation was initiated with a faculty and technician orientation workshop conducted by the author, covering the philosophy and operational procedure of each 5S pillar. A cross-functional implementation team comprising the laboratory technician, two senior faculty members, and a student representative from each workshop section was constituted to lead the 5S campaign.

Sort was executed through a systematic red-tagging exercise in which all laboratory items were evaluated for frequency of use and necessity. Approximately 30% of items in each workshop area were identified as redundant or unused and removed from the active workspace. Set in Order was implemented through the installation of shadow boards and foam-lined tool trays at each workstation, with every tool assigned a specific, labelled location. Colour coding was

applied to distinguish tool categories and to demarcate floor areas for workstations, material storage, movement corridors, and emergency exits. The Shine pillar was operationalised through a daily cleaning roster allocating cleaning responsibilities to student groups on a rotational basis, supported by a cleaning checklist posted at each workstation. Standardise was addressed through the development of visual standards posters displaying the correct organisation of each workstation area, mounted at eye level and laminated for durability. Sustain mechanisms included a weekly 5S audit protocol with scores recorded and displayed on a visible scoreboard, creating positive peer accountability among sections and shift groups.

4.3 Phase 2 — Value Stream Mapping and Flow Improvement (Semester 1, Months 4–6)

Value Stream Maps were constructed for each of the four workshop activity types, documenting the current-state sequence of activities from session start to practical task submission, with time measurements recorded for each step. The mapping process, conducted collaboratively with the laboratory technician and faculty members, identified two primary categories of flow waste: machine queuing, in which three to four students waited simultaneously for a single lathe or welding station; and sequential instruction delivery, in which the demonstrating faculty member was obliged to explain the same procedure to each student group individually.

Future-state VSMs were designed to address these wastes through two interventions. First, a rotational scheduling matrix was introduced, assigning students to machines in a planned rotation sequence to eliminate simultaneous queuing. Second, standardised demonstration videos and illustrated procedure sheets were developed for each practical task, reducing the time demand on faculty for repeated instruction and allowing students to self-refer during task execution.

4.4 Phase 3 — Visual Management and Standardised Work (Semester 2, Months 1–3)

Visual management was extended beyond 5S shadow boards to encompass a comprehensive visual information system throughout the laboratory. A large-format workflow progress board was installed at the laboratory entrance, displaying the rotational schedule, current session task, expected completion milestones, and machine availability status. Safety information was reorganised from A4-format text notices into colour-coded visual displays with pictographic representations of mandatory personal protective equipment, prohibited actions, and emergency procedures. Machine-specific operation sequence cards were laminated and affixed directly to each machine, enabling students to confirm correct setup and operational procedures without requiring faculty intervention for each instance.

Standardised Work Instructions (SWIs) were developed for the twelve most frequently performed practical tasks across the four workshop sections. Each SWI was structured to specify the quality standard required, the tools and consumables needed, the step-by-step operational procedure with safety checkpoints, and the inspection criteria for assessing task completion. SWIs were available in both printed form at workstations and as QR-code-accessible digital versions, accommodating students who preferred digital reference.

4.5 Phase 4 — Kaizen Cycles and Sustaining Mechanisms (Semester 2, Months 4–6)

Kaizen improvement cycles were institutionalised through monthly one-hour improvement meetings involving faculty, the laboratory technician, and rotating student representatives. Each meeting reviewed the current month's audit scores, equipment downtime records, and any safety observations, identified the top priority for improvement, and assigned a responsible owner and deadline. Improvements identified and implemented through Kaizen cycles during the study period included the installation of a simple pre-session equipment check card (reducing undetected equipment faults from 3.1 to 0.4 per month), the re-sequencing of the sheet metal practical tasks to eliminate a bottleneck at the shearing machine, and the introduction of a peer-checking protocol at key task completion points to reduce dimensional errors in finished components.

Table 1: 5S Implementation Summary — P.E.S. Polytechnic Mechanical Workshop Laboratory

5S Pillar	Action Taken	Measurable Outcome	Responsible
Sort (Seiri)	Identify and remove unused tools/equipment	Elimination of 30% redundant items	Students & Faculty
Set in Order (Seiton)	Designated places for all tools with labels	Tool retrieval time reduced by 65%	Lab Technician

5S Pillar	Action Taken	Measurable Outcome	Responsible
Shine (Seiso)	Daily cleaning schedule and inspection	Zero equipment damage from neglect	Students on rotation
Standardize (Seiketsu)	Visual standards and colour coding	Consistent lab environment maintained	Faculty & HOD
Sustain (Shitsuke)	Audit sheets and discipline culture	Ongoing compliance > 90%	All stakeholders

V. RESULTS AND DISCUSSION

5.1 Quantitative Performance Outcomes

Post-implementation measurements were conducted at the end of the second implementation semester using the same instruments and protocols employed in the baseline assessment. Table 2 presents the key performance indicators before and after framework implementation.

Table 2: Key Performance Indicators — Before and After Lean Framework Implementation

Key Performance Indicator	Before Lean	After Lean	Improvement
Average Session Setup Time (min)	18.4	5.2	71.7% reduction
Tool Search Time per Student (min)	6.8	1.2	82.4% reduction
Equipment Downtime per Week (hrs)	4.5	0.9	80.0% reduction
Students Completing All Tasks	68%	93%	+25 percentage points
Near-Miss Safety Incidents/Semester	4.2	0.6	85.7% reduction
Student Satisfaction Score (/10)	5.9	8.4	+42.4% improvement
Lab Audit Score (/100)	61	91	+49.2% improvement

The results demonstrate improvements across all measured parameters. The most pronounced gains were observed in tool search time (82.4% reduction, from 6.8 to 1.2 minutes per student per session) and safety near-miss incidents (85.7% reduction, from 4.2 to 0.6 per semester). Session setup time declined from 18.4 to 5.2 minutes, a 71.7% improvement attributable primarily to the 5S organisation and standardised pre-session equipment check. The practical task completion rate improved from 68% to 93%, representing a 25-percentage-point gain that reflects the combined effect of reduced idle time, clearer standardised work instructions, and improved machine availability through reduced unplanned downtime.

Student satisfaction improved from a mean score of 5.9 to 8.4 out of 10. Qualitative feedback gathered during the post-implementation survey indicated that students particularly valued the improved tool organisation, the clarity of standardised work instructions, and the perceived enhancement in safety. Faculty reported reduced time spent on crisis management and tool-issue disputes, creating capacity for more instructionally valuable interactions with students during practical sessions.

5.2 Comparative Analysis: Traditional vs. Lean Workshop

Table 3: Comparative Overview — Traditional vs. Lean-Integrated Mechanical Workshop

Parameter	Traditional Workshop	Lean-Integrated Workshop
Tool Accessibility	Random placement, frequent searching	5S-organized, shadow boards
Student Idle Time	High (10–20 min per session)	Reduced to < 3 min per session
Equipment Utilization	60–70%	85–92%
Safety Incidents	3–5 per semester	< 1 per semester
Practical Completion Rate	70–75%	90–95%
Documentation	Manual, inconsistent	Standardized, visual-aided
Student Throughput	Limited by workflow bottlenecks	Improved by 30–40%

5.3 Discussion of Findings

The magnitude of improvement achieved across all performance indicators substantially exceeds the results typically reported in similar interventions in service sector lean applications, and is consistent with the more dramatic gains reported in industrial lean implementations where starting conditions are equally disorganised. This suggests that the polytechnic workshop, characterised by low prior organisation, high variability in student activities, and limited existing documentation, represents a context where lean interventions yield returns well above the baseline reported in studies conducted in already-structured institutional environments.

The 5S component emerged as the single most impactful intervention, consistent with the theoretical position that 5S creates the foundational conditions of organisation and visual control upon which all subsequent lean tools depend. The Value Stream Mapping process was particularly valuable as a diagnostic tool, revealing waste patterns that were not apparent to practitioners immersed in day-to-day workshop operations. Several faculty members commented during the Kaizen meetings that the VSM exercise provided their first systematic view of the student experience through the entire session lifecycle, rather than from the perspective of individual activities.

The sustainability of improvements observed at the end of the second semester reflects the importance of the Kaizen cycle and audit mechanisms in the framework. In prior studies at other institutions where only 5S was implemented without sustaining mechanisms, improvement decay was evident within two to three months. The monthly Kaizen meetings and weekly audit protocol appear to have prevented this decay by maintaining active engagement with improvement activities and by creating accountability through the publicly displayed audit scores.

Challenges encountered during implementation included initial resistance from laboratory technicians concerned that 5S standards would constrain their operational flexibility, a concern addressed through their inclusion in the design of the 5S layouts and their designation as primary owners of the shadow board and tool organisation systems. Student discipline in adhering to 5S standards during the early weeks required active reinforcement from faculty, supported by the audit scoreboard which created positive competitive pressure between section groups.

VI. REPLICABILITY AND SCALABILITY CONSIDERATIONS

The framework developed and validated at P.E.S. Polytechnic is designed with replicability as an explicit objective. The total cost of implementation was modest, comprising primarily the materials for shadow boards, visual management displays, and laminated work instruction cards, estimated at approximately ₹18,000 to ₹25,000 for a four-section laboratory. No capital equipment expenditure was required. The implementation timeline of two semesters is compatible with the academic calendar of Indian polytechnic institutions under the Maharashtra State Board of Technical Education (MSBTE) framework.

The primary prerequisites for successful replication are faculty commitment to the implementation process, an institutional environment that supports faculty-led improvement initiatives, and the availability of at least one faculty member with sufficient familiarity with lean principles to lead the orientation and initial 5S campaign. The Kaizen meeting structure requires only one hour per month of faculty and technician time and generates its own sustaining motivation through the visible improvements it produces.

The framework is scalable across workshop types beyond the mechanical engineering laboratory. The underlying principles of 5S organisation, visual management, standardised procedures, and structured improvement cycles apply with equal validity to electronics, civil construction, and information technology laboratory settings within the polytechnic system. Adaptation would require only the redesign of the workshop-specific 5S layouts and standardised work instructions to reflect the tools, equipment, and tasks of the relevant discipline.

VII. CHALLENGES AND FUTURE DIRECTIONS

- Integration of Lean principles with digital laboratory management systems, enabling real-time tracking of equipment status, student task progress, and audit scores through a laboratory management software platform accessible to faculty and students via mobile devices.
- Extension of the Value Stream Mapping methodology to encompass the broader student learning journey across multiple semesters, identifying waste in the transitions between theory instruction, laboratory practice, and industrial training phases of the diploma programme.
- Development of a standardised Lean Maturity Assessment Tool (LMAT) calibrated for the polytechnic workshop context, enabling institutions to self-assess their current lean maturity level and prioritise framework components accordingly.
- Investigation of the impact of lean-organised workshop environments on the development of professional work habits and safety culture among students transitioning to industrial employment, through longitudinal follow-up studies with alumni.
- Exploration of low-cost automation of repetitive non-value-adding activities, such as tool inventory tracking and equipment maintenance scheduling, to further reduce technician workload and improve equipment availability.
- Scaling the framework through a train-the-trainer programme to facilitate adoption across the Maharashtra polytechnic system, with MSBTE supporting institutionalisation through inclusion of lean workshop management as a competency area in technical education quality audits.

VIII. CONCLUSION

This paper has presented the design, implementation, and quantitative evaluation of a Lean Manufacturing framework for productivity improvement in the polytechnic mechanical engineering workshop laboratory at P.E.S. Polytechnic, Chhatrapati Sambhajnagar. The framework, comprising 5S workplace organisation, Value Stream Mapping, visual management, standardised work instructions, and Kaizen-based continuous improvement, was implemented over two academic semesters and produced substantial, measurable improvements across all performance indicators.

Session setup time was reduced by 71.7%, tool search time by 82.4%, equipment downtime by 80.0%, and near-miss safety incidents by 85.7%. Practical task completion rates improved by 25 percentage points, and student satisfaction scores increased from 5.9 to 8.4 out of 10. These outcomes demonstrate convincingly that Lean Manufacturing principles, appropriately contextualised for the polytechnic educational setting, offer a powerful, cost-effective, and replicable methodology for transforming workshop laboratory productivity and safety.

The findings carry implications that extend beyond a single institution. Across the Indian polytechnic system, thousands of mechanical engineering workshop laboratories operate under conditions similar to those documented in this study's baseline assessment. The framework presented here, designed explicitly for the constraints of the polytechnic environment—limited budget, existing staff, standard academic calendar—offers a model that can be adopted without capital investment and within the capacity of any institution committed to systematic improvement.

Lean Manufacturing, first developed on the production floor to eliminate waste and create value for the industrial customer, proves equally applicable to the educational laboratory, where the objective is to eliminate every barrier between the student and the development of practical competency. The polytechnic workshop is, in essence, a production system whose product is a skilled and safety-conscious graduate. The principles that make production

systems excellent are the same principles that can make educational laboratories excellent. This study demonstrates that the transfer is not merely theoretical but practically achievable, measurably effective, and well worth the structured effort it demands.

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