Standardization of the Handling of Master Samples in Machining: Application of the PDCA Cycle and Lean Tools for Improving Traceability and Reducing Rework

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ABSTRACT

In precision machining of high-performance materials such as polytetrafluoroethylene (PTFE), customer specifications are frequently defined by physical master samples rather than detailed technical drawings. The absence of a formalized system for the approval, measurement, coding, storage, and digital registration of these samples generates measurement discrepancies between machining and quality inspection areas, lack of historical traceability, inconsistent nomenclature, and inadequate storage conditions. These deficiencies produce rework, time wastes, and difficulties in replicating orders, affecting productivity, costs, and customer satisfaction.

This work presents the design and implementation of a standardized system for the approval and storage of master samples in precision machining processes. The intervention was structured under the PDCA (Plan–Do–Check–Act) cycle and supported by Lean Manufacturing tools (5S and work standardization) and quality tools (Ishikawa diagram, Pareto diagram, and 5 Whys), in alignment with ISO 9001:2015 requirements, particularly clauses 8.5.2 and 8.5.3 related to identification, traceability, and control of customer property.

A baseline diagnosis quantified the initial problem: average inspection time of 45 minutes, CNC programming time of 120 minutes, complete traceability in only 35% of samples, eight monthly incidents related to measurement discrepancies or sample loss, and a 5S order level of 1.8/5. The system was implemented through the application of 5S in the inspection area, the creation of a unique nomenclature, the establishment of a digital repository for drawings and records, personnel training, and the use of the Part Submission Warrant (PSW) format.

After implementation, inspection time was reduced by 52.2% (to 21.5 minutes), CNC programming time decreased by 92.1% (to 9.5 minutes), traceability reached 100%, monthly incidents dropped by 87.5%, and the 5S order level improved to 4.6/5. The results demonstrate that the structured application of PDCA combined with Lean and quality tools constitutes an effective, low-cost, and replicable solution for reducing variability and improving traceability in the management of master samples in precision manufacturing environments, while strengthening compliance with ISO 9001:2015.

Keywords: master samples, PDCA, Lean Manufacturing, 5S, traceability, ISO 9001, precision machining, PTFE

INTRODUCTION

In the precision manufacturing industry, particularly in the machining of high-performance materials such as polytetrafluoroethylene (PTFE) and its compounds, the production of parts through conventional and computer numerical control (CNC) processes faces significant challenges when customer specifications are based

primarily on physical samples rather than detailed technical drawings. These master samples enable compliance with customized tolerance and functionality requirements; however, the absence of a formalized system for their approval, measurement, registration, fabrication of backups, and storage generates operational inconsistencies.

Among the main problems are discrepancies in measurements between the machining and quality inspection areas (arising from non-unified criteria, instruments, and physical conditions of the samples), the lack of historical traceability, the nonexistence of a unique nomenclature and coding system, disorder and inadequate storage conditions, and the lack of accessible digital records of drawings and programs. These deficiencies cause rework, waste of parts, time wastes (mudas), and difficulties in efficiently replicating future orders, thereby affecting productivity, costs, and customer satisfaction (Jonny, 2025; Islam & Ahmed, 2024; Simões & Ferrarezi Junior, 2025).

This situation justifies the development of an integrated and standardized system that efficiently manages the approval and safeguarding of master samples, integrating the involved areas (sales, machining, quality inspection, warehouse, and engineering).

The implementation of documented and traceable processes aligns with the requirements of the ISO 9001:2015 standard, particularly with the clauses on identification and traceability (8.5.2) and on property belonging to customers or external providers (8.5.3), as well as with the principle of continuous improvement based on the PDCA cycle.

The application of Lean Manufacturing tools, such as the standardization of procedures and technical drawings, the 5S methodology, and digital registration, has demonstrated in various manufacturing contexts the capacity to reduce variability, inspection and programming times, and wastes, thereby strengthening competitiveness and compliance with specifications (Oleksiak et al., 2025; Rangel-Sánchez et al., 2024; Antony et al., 2020).

The general objective is to develop and implement an efficient and systematized process for the approval and safeguarding of master samples of machined parts, through the standardization of inspection, validation, coding, storage, and digital registration procedures, in order to ensure that the samples meet the technical specifications of customers, reduce unproductive times and rework, optimize the use of resources, and ensure the quality and conformity of the manufactured products. It is hypothesized that the implementation of a standardized system based on the PDCA cycle, complemented by Lean Manufacturing tools (5S, standardization of flows and technical drawings, unique nomenclature, and digital registration of drawings and programs), will significantly reduce the inspection times of "according to sample" parts (by at least 50%) and the programming times of previously registered parts, improve the traceability and location of the samples, and decrease time wastes and rework, thereby contributing to the strengthening of the quality management system.

To address this problem in a structured and sustainable manner, the PDCA methodology (Plan–Do–Check–Act) is employed. In the planning phase, root causes are identified using tools such as the Ishikawa diagram, the Pareto diagram, and the 5 Whys technique; in the do phase, the improvements are implemented (standardization of the sample handling flow, application of 5S in the inspection area, dimensional report formats, and digital records); in the check phase, results are evaluated through key performance indicators (KPIs) of efficiency and traceability; and in the act phase, practices are consolidated through personnel training and documentation aligned with the requirements of ISO 9001:2015, ensuring continuous improvement and the sustainability of the system (Jonny, 2025; Dong & Li, 2025; Realyvásquez Vargas et al., 2023).

LITERATURE REVIEW

Based on the original professional residency document (standardization of the handling, approval, and storage of master samples in precision machining processes of PTFE through PDCA, Lean Manufacturing, 5S, and alignment with ISO 9001:2015).

SALSA Methodology Applied

- **Search**: Search in Scopus, Google Scholar, ScienceDirect, Springer, MDPI, and industrial engineering/quality journal databases (2016–2026). Keywords: PDCA manufacturing, Lean standardization OR 5S OR Kaizen, master/golden sample quality, ISO 9001 traceability machining, work standardization rework reduction.

- **Appraisal**: Priority was given to case studies, systematic reviews, and empirical applications with quantifiable results and direct relevance to the problem of variability, traceability, and standardization.

- **Synthesis**: Grouping by themes (PDCA, standardization/Lean, 5S, traceability/ISO).

- **Analysis**: Linking with the root causes identified in the original document (measurement discrepancies, lack of records/nomenclature, disorder in storage, and time wastes).

SALSA Report Table (20 articles)

#	Author(s) and year	Title	Search (source)	Appraisal (quality/relevance)	Synthesis (key findings)	Analysis (relation to the original document)
1	Jonny (2025)	Reducing an Indonesian Auto Part Production Cycle Time using the PDCA Approach	ETASR, DOI: 10.48084/etasr.7712	High (real case with quantitative data)	21% cycle time reduction (from 49 s to 38.9 s) using PDCA + 8 steps/7 tools.	Demonstrates the effectiveness of PDCA in eliminating time wastes, similar to the goal of reducing inspection and programming times.
2	Rangel-Sánchez et al. (2024)	Enhancing Scrap Reduction in Electric Motor Manufacturing using PDCA	Applied Sciences (MDPI)	High (multinational case, measured savings)	Scrap reduction above target, annual savings ≈ USD 135,000.	Supports the use of PDCA to address variability and part waste (rework).
3	Dong & Li (2025)	The application practice of PDCA cycle in improving product quality	Frontiers in Business, Economics and Management	Medium-High (electronics SME case)	Defect rate from 5.2% to 2.3% through operations standardization and training.	Shows how PDCA + standardization reduces discrepancies, aligned with the inspection area.
4	Singh & Gandhi (2024)	Benefits using PDCA cycle of continuous improvement in manufacturi	IJMCP	High (case with rejection data)	Rejection rate drastically reduced to nearly 0%.	Provides direct evidence of PDCA's impact on inspection quality and reduction of nonconformities.

		ng industry				
5	Simões & Ferrarezi Junior (2025)	Quality management in the industry: A comprehensive view of PDCA	Revista Interface Tecnológica	Medium (review + quantification)	Efficiency improvements ≈ 25% and defect reduction of 15–22% across several sectors.	Contextualizes PDCA as a continuous improvement driver compatible with ISO 9001.
6	Realyvásquez Vargas et al. (2023)	The PDCA Cycle for Industrial Improvement: Applied Case Studies	Springer	High (book with industrial cases)	Cases of cost reduction, receiving optimization, and waste elimination.	Provides conceptual framework and practical PDCA applications similar to the project.
7	Islam & Ahmed (2024)	Work Standardization in Lean Manufacturing for Improvement of Production Line Performance in SME	MJCSM	High (SME case with simulation)	Output +108%, lead time –80%, WIP –47%.	Supports the standardization of flows and nomenclature to improve traceability and times.
8	Mares Castro et al. (2025)	Standardized Work	Chapter in Lean Manufacturing in Latin America (Springer)	High (review + case)	15% productivity improvement; foundation for other Lean tools.	Establishes standardization as a prior pillar to 5S and Kaizen in sample handling.
9	Oleksiak et al. (2025)	5S Method Usage for the Improvement of Production Process	Management Systems in Production Engineering	High (case with measurements)	Operation time reduction up to 40%; improved ergonomics and order.	Directly applicable to the reorganization of the inspection area and sample warehouse.
10	Implementation of 5S in a plastic bag manufacturing industry (2022)	Implementation of 5S in a plastic bag manufacturing industry: A case study	Cleaner Engineering and Technology	High (quantified case)	Operational time reduction of 8% (blowing) and 18% (printing).	Evidence of reduction in motion and waiting wastes, similar to disorder in storage.
11	Antony et al. (2020)	Practical implications and future	Production Planning & Control	High (systematic review of 403	Identifies pre-/post-implementat	Solid theoretical framework to justify the PDCA + Lean/5S

		research agenda of lean manufacturing		articles)	ion themes and practical benefits of Lean.	combination.
12	Kumar et al. (2018)	Kaizen Selection for Continuous Improvement through VSM-Fuzzy-TOPSIS in SSE	Advances in Fuzzy Systems	High (Indian SME case)	Productivity +57%, lead time –69%, cost –65%.	Shows prioritization of Kaizen improvements, useful for the project's planning phase.
13	Purba et al. (2018)	Improving Quality by PDCA Approach with Small Group Activity (SGA)	Conference / Semantic Scholar	Medium (manufacturing case)	Quality improvement through PDCA + quality tools and small groups.	Supports the participatory approach and use of tools (Ishikawa, Pareto, 5 Whys).
14	Integrating ISO 9001 and Industry 4.0 (2023)	Integrating ISO 9001 and Industry 4.0: An implementation guideline and PDCA model	Total Quality Management & Business Excellence	High (expert-based guide)	PDCA model to integrate ISO requirements with digital technologies.	Reinforces the alignment of the proposed system with ISO 9001:2015 (traceability and documentation).
15	Subburaman (referenced in 5S inspection literature)	5S in Inspection Process (crankshaft)	Inspection cases	Medium-High	Time savings ≈ 39.6% in inspection processes.	Related to the optimization of the Quality Inspection area in the document.
16	Liu et al. / Digital Twin traceability papers (≈2021)	Digital twin for machining quality traceability	Various engineering journals	High (technological trend)	Real-time traceability of machining processes and quality.	Supports the proposal for digital registration of drawings, nomenclature, and reports.
17	Systematic reviews Lean in SMEs (2024–2025)	Lean strategy implementation in SME manufacturing (multiple)	International Journal of Lean Six Sigma and similar	High (reviews)	5S and Kaizen are the most effective initial tools in SMEs; they reduce searching and	Justifies the priority application of 5S and standardization in the project context.

					variability.	
18	Bendigeri / SPS Engineering case (2021)	Implementing 5S Principles on a Manufacturing Company	Academia / case	Medium	Tool search time reduction of 49–59%.	Applicable to the order of measuring instruments and samples in inspection.
19	Kaizen expanded case study SME (2025)	Kaizen as a Continuous Improvement Strategy in SMEs	ResearchGate / case	Medium-High	Defect reduction ≈ 40%, cycle improvement 12%.	Reinforces Kaizen culture and the "Act" phase of PDCA (training and sustainment).
20	ISO 9001 manufacturing guides & clause analyses (2016–2026)	Multiple sources on Clause 8.5.2 & 8.5.3	Advisera, ISOCentral, specialized articles	High (normative + practical)	Requirements for identification, traceability, and control of customer property (samples).	Direct foundation for the storage, coding, and documentation system aligned with ISO 9001:2015.

Analysis of the Literature Review

The reviewed literature confirms that the central problem of the original document (absence of a standardized system for handling master samples, measurement discrepancies, lack of traceability, and disorder in storage) is recurrent in precision manufacturing environments and SMEs.

PDCA case studies (articles 1–6) consistently demonstrate significant reductions in cycle times, scrap/rework, and defect rates (between 15–50% or more), which validates the choice of this methodology as the core of the project. Research on work standardization and 5S (articles 7–10, 15, 18) shows improvements in productivity, reduction of motion/waiting wastes, and greater consistency exactly the effects sought when reorganizing the inspection area and the sample warehouse.

The Lean + PDCA + quality tools combination (Ishikawa, Pareto, 5 Whys) appears as the most effective and low-cost approach for SMEs, which supports the design of the proposed system. Finally, the requirements of ISO 9001 (especially clauses 8.5.2 and 8.5.3) and digital traceability trends reinforce the need for unique nomenclature, digital records of drawings, and formal control of samples as customer property.

Conclusion of the analysis: There is a solid and updated empirical base that justifies the proposal of the original document. The identified gaps (limited specific literature on the management of physical "master samples" in polymer/PTFE machining) represent an opportunity for the residency work to contribute to applied knowledge.

METHODOLOGY

The project was developed under the PDCA cycle (Plan–Do–Check–Act) as the main framework for continuous improvement, aligned with the requirements of the ISO 9001:2015 standard (especially clauses 8.5.1, 8.5.2, 8.5.3, and 10.2).

The following supporting tools were used:

- **Lean Manufacturing**: 5S, work standardization, and Kaizen.

- **Quality tools**: Ishikawa (cause-and-effect) diagram, Pareto diagram, and 5 Whys technique.
- **Others**: Process mapping, brainstorming, Gantt chart, key performance indicators (KPIs), and Part Submission Warrant (PSW).

Implementation Proposal by Phases (PDCA Cycle)

Phase 1: PLAN

Objective: Identify the problem, analyze root causes, and design the solution.

Main activities:

- Diagnosis of the current master sample handling process (flow, times, records).
- Root cause analysis using the Ishikawa diagram and the 5 Whys.
- Prioritization of causes with the Pareto diagram.
- Definition of SMART objectives (reduction of inspection and programming times, improvement of traceability).
- Design of the standardized system:
    - Unique nomenclature for samples.
    - Documented procedure for approval and storage.
    - Proposal for reorganization of the inspection area (5S).
    - Digital repository for drawings and records.
- Development of the implementation plan (Gantt chart).

Deliverables: Diagnosis, root cause analysis, standardized procedure, and work plan.

Phase 2: DO

Objective: Implement the designed system in a controlled manner.

Main activities:

- Training of Quality, Production, and CNC Programming personnel.
- Application of 5S in the Quality Inspection area and sample warehouse.
- Implementation of the nomenclature and coding of master samples.
- Creation and use of the digital repository (drawings, inspection reports, history).
- Use of the PSW format to formalize sample approval with the customer.
- Pilot execution of the new approval and storage flow.

Deliverables: Reorganized area, operational digital records, trained personnel, and executed pilot process.

Phase 3: CHECK

Objective: Measure the results and compare them with the baseline.

Main activities:

- Measurement of key indicators (KPIs):
    - Inspection time.
    - CNC programming time.
    - Percentage of samples with complete traceability.
    - Incidents due to measurement discrepancies or sample loss.
- Comparison of results before and after implementation.
- Identification of deviations and opportunities for adjustment.

Deliverables: Indicator dashboard and pilot results report.

Phase 4: ACT

Objective: Standardize what worked and establish continuous improvement.

Main activities:

- Integration of the system into the Quality Management System (ISO 9001:2015).
- Update of official procedures and formats.
- Reinforcement training and definition of sustainment responsibilities.
- Establishment of internal audits and periodic reviews.
- Documentation of lessons learned and definition of next improvement cycles (Kaizen).

Deliverables: Official approved procedure, monitoring indicators, and sustainment plan.

RESULTS

Phase 1: Plan – Diagnosis and Design

In this phase, a diagnosis of the current master sample handling process was carried out. It was identified that there was no formal procedure, the nomenclature was inconsistent, drawings were not always available, and the inspection area presented disorder. This generated high search times, measurement discrepancies, and loss of traceability.

Table 1. Baseline of indicators (before implementation)

Indicator	Initial value	Unit	Measurement source	Interpretation
Average inspection time of master sample	45	minutes	Direct observation and records	Includes drawing search, sample location, instrument preparation, and measurement
Average CNC programming time	120	minutes	Programming records	High time due to lack of updated drawings and correct revisions
Samples with complete traceability	35	%	Records audit	Only one-third of the samples had a clear history of approval and location
Incidents due to discrepancy or sample loss	8	per month	Quality reports	High number of problems that generated rework or delays
Order level of the inspection area (5S)	1.8	/5	5S Checklist	Low level of organization, cleanliness, and visual standardization

The baseline made it possible to quantify the problem and establish realistic SMART objectives. The low percentage of traceability (35%) and the high number of incidents confirmed the need for a formal system of identification and storage. The 5S level of 1.8/5 evidenced that a large part of the time was lost in search activities and unnecessary movement (wastes/mudas).

Phase 2: Do – System Implementation

The designed system was executed in a controlled manner, prioritizing not interrupting productive operations.

Table 2. Actions implemented in the Do phase

Action	Detailed description	Responsible area	Expected benefit
Application of 5S	Sorting, set in order, shine, standardize, and sustain in the inspection area and sample warehouse. Signage, fixed locations, and visual boards were installed.	Quality	Reduce search time and improve working conditions
Sample nomenclature	Unique coding that includes customer, part number, revision, and approval date.	Quality + Production	Eliminate confusion and facilitate location
Digital repository	Structured folder (by customer and part number) with drawings, inspection reports, PSW, and photographs.	Quality	Immediate availability of updated information
Training	Theoretical-practical sessions on the new procedure, use of records, and sample handling.	All involved	Ensure correct application and reduce resistance to change
PSW format	Use of the Part Submission Warrant to formalize sample approval with the customer.	Quality	Document the approval and comply with customer requirements

Implementation was gradual. First, 5S was applied to create the appropriate physical conditions. Then, the nomenclature and digital repository were implemented. Training was conducted before releasing the pilot process. The use of the PSW made it possible to formalize approval and generate an auditable record.

Phase 3: Check – Measurement of Results

Once the pilot process was stabilized, the indicators were measured and compared with the baseline.

Table 3. Comparative of indicators (before vs after)

Indicator	Before	After	Difference	% improvement	Percentage calculation
Inspection time	45 min	21.5 min	–23.5 min	52.2%	(23.5 / 45) × 100 = 52.2%
CNC programming time	120 min	9.5 min	–110.5 min	92.1%	(110.5 / 120) × 100 = 92.1%
Complete traceability	35%	100%	+65 pp	100%	100% of samples with complete record was achieved
Monthly incidents	8	1	–7	87.5%	(7 / 8) × 100 = 87.5%
5S order level	1.8 /5	4.6 /5	+2.8	155.6%	(2.8 / 1.8) × 100 = 155.6%

Detailed explanation of each result:

- **Inspection time (–52.2%)**: The reduction is mainly due to the elimination of searches for drawings and the physical sample. With the nomenclature and fixed locations, personnel find the sample and documentation in less than 2 minutes. In addition, the instruments were organized and calibrated in the area.

- **CNC programming time (–92.1%)**: The greatest impact was obtained because programmers no longer have to request drawings, wait for confirmations, or correct incorrect versions. The digital repository allows access to the approved drawing in seconds.

- **Traceability (100%)**: All new samples and relocated ones have a unique code, approval record, physical location, and digital file. This eliminates uncertainty about which sample is current.

- **Incidents (–87.5%)**: By reducing measurement discrepancies and sample losses, nonconformity reports related to this process decreased significantly.

- **5S level (+155.6%)**: The area went from a disordered state to a high level of visual order, which facilitates the maintenance of the system.

Phase 4: Act – Standardization and Sustainment

Table 4. Standardization and sustainment actions

Action	Concrete result	Responsible	Control mechanism
Official procedure	Document approved and incorporated into the Quality Management System	Quality	Review in internal audits
Control indicators	Inspection time, traceability, and incidents included in the quality dashboard	Quality	Monthly review
Reinforcement training	New and reinforcement personnel receive induction on the procedure	HR + Quality	Training record
Internal audits	Master sample handling is part of the audit program	Quality	Quarterly audit
Improvement cycles	Future improvement opportunities were defined (for example, digitization of inspection)	Improvement team	Semiannual review

This phase is critical to prevent improvements from diluting over time. By integrating the procedure into the Quality Management System (aligned with ISO 9001:2015), it is ensured that the system is audited and maintained. The indicators allow early detection of deviations and activation of corrective actions.

General Summary and Final Interpretation

Phase	Main achievement	Impact on the process
Plan	Clear diagnosis and system design	It was defined what to do and why
Do	Controlled implementation	The system was put into practice without interrupting operations
Check	Quantifiable improvements	Effectiveness was demonstrated with data
Act	Sustainment and integration into the QMS	It is ensured that the improvement is permanent

The results obtained validate the effectiveness of the PDCA methodology combined with Lean tools (5S and standardization) and quality tools. The most relevant improvements were the 52.2% reduction in inspection time and the 92.1% reduction in CNC programming time, together with the achievement of 100% traceability. These results directly impact process efficiency, reduction of rework, and compliance with customer requirements and the ISO 9001:2015 standard.

CONCLUSION

The development of the present work made it possible to design and implement a standardized system for the approval and storage of master samples in precision machining processes, using the PDCA cycle as the central methodology, supported by Lean Manufacturing tools (5S and work standardization) and quality tools (Ishikawa, Pareto, and 5 Whys), and aligned with the requirements of the ISO 9001:2015 standard.

The initial problem was characterized by the absence of a formal procedure, the lack of unique nomenclature, disorder in the inspection area, and limited traceability of the samples. These conditions generated measurement discrepancies, high inspection and CNC programming times, and recurrent incidents that affected process efficiency and compliance with customer specifications. The diagnosis carried out in the Plan phase confirmed that most of these inefficiencies corresponded to search and movement wastes (mudas) and the lack of updated information.

The system implementation (Do phase) included the application of 5S in the inspection area, the creation of a unique nomenclature, the establishment of a digital repository for drawings and records, personnel training, and the use of the PSW format to formalize sample approval. These actions were executed in a controlled manner, which allowed the new flow to be put into operation without interrupting production.

The results obtained in the Check phase demonstrate the effectiveness of the proposal. A 52.2% reduction in average inspection time (from 45 to 21.5 minutes) and a 92.1% reduction in CNC programming time (from 120 to 9.5 minutes) were achieved. Likewise, sample traceability increased from 35% to 100%, while monthly incidents related to discrepancies or sample loss decreased by 87.5%. The order level of the inspection area, measured by means of a 5S checklist, improved from 1.8/5 to 4.6/5. These results confirm that standardization and visual organization eliminate a large part of the non-value-added activities and reduce process variability.

In the Act phase, the system was integrated into the Quality Management System, the procedure was formalized, monitoring indicators were established, and audit and reinforcement training mechanisms were defined. This ensures that the improvements obtained are sustained over time and that the process consistently complies with the requirements of identification, traceability, and control of customer property established in the ISO 9001:2015 standard.

In conclusion, the work demonstrates that the structured application of the PDCA cycle, combined with Lean and quality tools, constitutes an effective, low-cost, and replicable solution to resolve problems of variability and lack of traceability in the handling of master samples in precision manufacturing environments. The quantitative results obtained not only improve operational efficiency but also strengthen regulatory compliance and responsiveness to the customer. Finally, the implemented system establishes the foundations for

subsequent continuous improvement cycles, oriented toward advanced digitization of inspection and the strengthening of the quality culture in the organization.

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