Economic Impact of Implementing a PDCA-Based Traveler Sheet for Cost Reduction in a CNC Machining Area

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DOI: https://doi.org/10.47772/IJRISS.2026.102500018

Received: 26 October 2026; Accepted: 31 October 2026; Published: 16 November 2026

ABSTRACT

Manufacturing companies continuously seek strategies that improve operational efficiency while reducing production costs and increasing profitability. However, the absence of standardized production control mechanisms limits process traceability, increases rework, generates material waste, and negatively affects financial performance. This applied research evaluates the economic and operational impact of implementing a traveler sheet (HV-CNC-001) under the Plan–Do–Check–Act (PDCA) methodology in the CNC. A mixed-method approach with a predominantly quantitative design was employed using a pretest–posttest experimental comparison over six months. The implementation was evaluated through six key performance indicators related to production control, traceability, setup time, rework, and information management. Statistical analyses included Student's t-test and the Wilcoxon signed-rank test.

The results showed significant improvements across all evaluated indicators, including a 50.0% reduction in information search time, a 39.6% reduction in traceability-related defects, a 45.5% decrease in specification rework, and an 18.8% reduction in total production cycle time. From an economic perspective, these operational improvements generated estimated annual savings of MXN $706,920, demonstrating that standardized production control contributes directly to cost reduction, productivity improvement, and enhanced manufacturing competitiveness. The findings confirm that integrating PDCA with standardized production documentation not only strengthens operational management but also creates measurable financial value, supporting decision-making aimed at continuous improvement and sustainable industrial competitiveness.

Keywords: PDCA, traveler sheet, CNC machining, cost reduction, production control

INTRODUCTION

The growing competitiveness of manufacturing markets has compelled organizations to orient their strategies toward resource optimization, the reduction of operating costs, and increased productivity, while simultaneously maintaining high-quality standards. In this context, the efficiency of production processes has become a determining factor for business profitability, since small variations in operating times, waste levels, or the occurrence of rework can represent significant economic losses and affect the competitive capacity of organizations. The transition toward smart manufacturing and Industry 4.0 models has increased the need to establish management systems that enable production processes to be controlled, monitored, and continuously improved through reliable and timely information. (Taylor & Francis Online)

Within the manufacturing industry, Computer Numerical Control (CNC) machining operations constitute one of the stages with the greatest economic impact due to the high value of equipment, the costs associated with cutting tools, energy consumption, specialized labor, and high-precision materials. Consequently, any deviation in the manufacturing process, whether caused by errors in specifications, traceability losses, unproductive time, or failures in communication between the different stages of the process, directly increases production costs and decreases the overall efficiency of the system. Various studies indicate that quality management in manufacturing must evolve from an approach based solely on inspection toward preventive models supported

by information, traceability, and continuous improvement, making it possible to reduce costs derived from poor quality and strengthen decision-making. (Taylor & Francis Online)

One of the main challenges of current production systems is to ensure the complete traceability of each manufacturing order throughout all process operations. The absence of standardized mechanisms for recording information related to materials, machining parameters, intermediate inspections, and the sequence of operations increases the likelihood of generating nonconforming products, rework, waste, and downtime, elements that represent a significant portion of hidden manufacturing costs. From an economic perspective, these costs not only affect the company's profitability but also limit the efficient utilization of installed capacity, reduce labor productivity, and decrease competitiveness compared with organizations that incorporate data-driven management tools. Likewise, recent literature recognizes traceability as a strategic element for ensuring operational continuity, improving information reliability, and strengthening the efficiency of industrial supply chains. (NIST Cybersecurity)

In this scenario, the implementation of continuous improvement tools represents an effective alternative for reducing economic losses caused by poorly controlled processes. Among these tools, the Plan–Do–Check–Act (PDCA) cycle has proven to be a widely used methodology for identifying root causes, implementing improvement actions, verifying results, and standardizing successful processes. Its application promotes the reduction of defects, increased productivity, and the strengthening of quality management systems, making it possible to transform operational information into decisions aimed at efficiency and the optimal utilization of available resources. Recent research highlights that integrating the PDCA cycle with technologies and document management tools constitutes an effective mechanism for increasing control capabilities and facilitating continuous improvement processes in manufacturing environments. (Taylor & Francis Online)

Among the tools used to strengthen production control, the traveler sheet stands out as a document that accompanies each manufacturing order throughout all stages of the production process and consolidates information regarding technical specifications, sequence of operations, responsible personnel, quality inspections, materials used, and execution times. In addition to facilitating communication among the different production areas, this document constitutes an essential source of information for generating performance indicators, analyzing deviations, and identifying improvement opportunities. When its implementation is developed under a structured methodology such as the PDCA cycle, the traveler sheet ceases to be merely an administrative form and becomes a management instrument capable of generating strategic information for reducing operating costs and strengthening the organization's financial performance.

Despite the widespread application of the PDCA cycle in studies related to continuous improvement, a significant portion of existing research focuses its analysis on operational indicators, such as defect reduction, increased quality, or reduced process times, while the economic impact derived from such improvements receives considerably less attention. Consequently, a knowledge gap persists regarding the financial quantification of the benefits obtained through the implementation of document control systems in CNC manufacturing processes, particularly with regard to the reduction of costs associated with rework, traceability losses, unproductive time, and the utilization of installed capacity. This limitation makes it difficult for organizations to have objective evidence to justify investments aimed at strengthening their production management systems.

From this perspective, the present research aims to evaluate the economic impact of implementing a traveler sheet based on the PDCA cycle for cost reduction in a CNC machining area, through applied research with a pretest–posttest experimental design. In addition to analyzing the effects on operational indicators related to traceability, cycle times, rework, and process efficiency, the study incorporates a cost-benefit analysis that quantifies the economic savings generated by the intervention. In this way, the research provides empirical evidence that standardizing production control not only improves operational performance but also constitutes an economically viable

Research Elaborations

The competitiveness of manufacturing organizations depends on their ability to efficiently manage available resources, reduce operating costs, and ensure product quality throughout all stages of the manufacturing process.

In this context, production control constitutes one of the fundamental elements for ensuring that operations are carried out in accordance with established standards, allowing the monitoring of time, materials, human resources, and equipment with the purpose of optimizing the performance of the production system. According to recent literature, the digitalization of manufacturing processes and the implementation of standardized control mechanisms promote data-driven decision-making, increase productivity, and strengthen business competitiveness (Sony et al., 2023).

One of the main factors affecting profitability in manufacturing processes corresponds to costs of poor quality, understood as those economic resources allocated to correcting errors, performing rework, replacing defective products, conducting additional inspections, or addressing failures resulting from deficiencies in the production process. These costs represent losses that do not add value to the product and reduce the financial efficiency of organizations. Various studies indicate that the adoption of preventive quality management systems makes it possible to significantly reduce these costs by strengthening traceability and standardizing operations (Antony et al., 2022).

In CNC machining processes, where strict dimensional tolerances and high-value equipment are involved, traceability acquires strategic importance by making it possible to identify the complete history of each production order, from material receipt to final inspection. The availability of reliable information throughout the process facilitates the timely detection of deviations, reduces information retrieval times, and decreases the likelihood of errors associated with incorrect specifications or incomplete operation sequences. In this regard, the traveler sheet constitutes a document control tool that integrates technical, operational, and quality information, making it possible to strengthen communication among the different workstations and generate evidence for the analysis of performance indicators.

As a continuous improvement methodology, the Plan–Do–Check–Act (PDCA) cycle provides a systematic structure for planning improvements, implementing actions, verifying results, and standardizing successful practices. Its application in industrial environments has been shown to contribute to waste reduction, resource optimization, and increased productivity, becoming a widely used tool within quality management and lean manufacturing systems (Fonseca et al., 2023).

From an economic perspective, integrating PDCA with document control tools makes it possible to transform operational improvements into quantifiable financial benefits through the reduction of rework, unproductive time, and costs associated with poor quality.

Under this approach, the present research is based on the assumption that implementing a traveler sheet based on the PDCA cycle not only strengthens the control and traceability of the production process but also constitutes an economically viable strategy for reducing operating costs, increasing productivity, and improving the financial performance of manufacturing organizations.

Review Objective

To identify, select, and synthesize the available scientific and technical evidence on the design, implementation, and impact of traveler sheets (travel cards / job travelers / route sheets) as a tool for production control, traceability, and visual management in manufacturing environments, with an emphasis on CNC machining processes and continuous improvement methodologies (PDCA / Lean).

Search Protocol and Criteria

Search Strategy

Databases consulted: Google Scholar, ScienceDirect, SciELO, Redalyc, TecNM and institutional repositories, Semantic Scholar. Period: 2015–2026. Languages: Spanish and English.

Combined keywords: ("hoja viajera" OR "travel card" OR "job traveler" OR "shop traveler" OR "route card" OR "traveler sheet") AND ("control de producción" OR "production control" OR "trazabilidad" OR "traceability" OR CNC OR "maquinado" OR "PDCA" OR "Lean" OR "visual management").

Inclusion Criteria

Articles, theses, or technical reports addressing traveler sheets / travel cards / route sheets in manufacturing.

Studies on traceability, production control, or visual management in CNC or precision processes.

Applications of the PDCA / PHVA cycle or Lean tools (VSM, Ishikawa, Pareto) in the improvement of production processes.

Publications with empirical evidence, case studies, or reviews between 2015 and 2026.

Exclusion Criteria

Purely commercial documents without implementation data or measurable results.

Articles on travel cards for travel purposes (government/corporate) unrelated to production.

Publications prior to 2015, except for classical methodological references.

PRISMA Flow Diagram

Identification: ≈ 165 records obtained from databases and repositories.

Screening: 78 records after removing duplicates and irrelevant titles.

Eligibility: 42 full-text documents evaluated according to the inclusion/exclusion criteria.

Included: 20 documents (articles, theses, and reviews) selected for the narrative synthesis.

Table 1. Literature Report

No.	Author(s) / Year	Title / Type	Main Contribution to the Topic
1	Galvan, I. M. (2019)	Engineering Thesis – Human factor control	Defines the traveler sheet as a production control document that centralizes operational, quality, and traceability information.
2	Alonso, J. M. (2022)	Thesis – Operational control web system	Positions the traveler sheet as a pillar of visual management (Visual Management) within Lean Manufacturing.
3	Calderón, L. S. (2022)	Article – Production planning and control	Establishes production control as the measurement of actual performance against standards and corrective actions.
4	Ibrahim, M. M. (2023)	Article – Implementing Travel Card System	Demonstrates a reduction in material waste and an improvement in efficiency through a Travel Card System in industry.
5	Patil et al. (2023)	Book chapter – Paperless SOPs and Travelcard	Analyzes the transition of SOPs and travel cards to paperless formats under Green Manufacturing initiatives.
6	Schuitemaker & Xu (2020)	Review – Product traceability in manufacturing	Reviews frameworks, enabling technologies, and implementation of product traceability systems in manufacturing.
7	Garrido Campos & Hardwick (2006)	Article – Traceability information model for CNC	Proposes a traceability information model linking CNC, CAD, and CAM reports to ensure product characteristics.
8	Marín, J. (2024)	Thesis – Traceability in supply chains	Defines traceability as the ability to track history, location, and components throughout the production chain.

9	Souza, D. F. (2025)	Article – PDCA Cycle as a strategy	Describes PDCA as a continuous learning methodology through iterations of planning, execution, verification, and action.
10	González & Buitrón (2023)	Article – PDCA Cycle in process optimization	Applies the PHVA (PDCA) cycle to optimize product properties, demonstrating its structuring usefulness.
11	Rubio et al. (2025)	Thesis – KPI-based evaluation system	Develops a KPI system to improve decision-making and talent development in manufacturing SMEs.
12	Tachong et al. (2025)	Article – Ishikawa diagram in problem solving	Applies a cause-and-effect diagram (6M) for the systematic identification of root causes in business environments.
13	García, J. I. (2023)	Thesis – Good manufacturing practices manual	Links production control with assurance of dimensional conformity under precision tolerances.
14	Méndez & Solís (2025)	Article – Production cost control	Relates production control to cost reduction strategies and best practices in manufacturing.
15	Vasques & Castañeda (2023)	Article – VSM in manufacturing processes	Applies Value Stream Mapping to identify waste and design a future state of the value stream.
16	Neway Precision (2025)	Case – PDCA in high-precision CNC machining	Integrates PDCA into CNC quality control: CTQ planning, dimensional verification, and standardization.
17	Azumuta / industria digital (2025-26)	Cases – Digital Manufacturing Travelers	Reports 27% improvements in productivity and 63% in quality by digitizing travelers with the integration of smart tools.
18	Kaizen ISO Consulting (2026)	Technical article – Job Travelers and ISO 9001	Demonstrates that the job traveler consolidates evidence of clauses 8.5.1, 8.5.2, and 8.6 of ISO 9001 in a single document.
19	SGS / MasterControl (2025-26)	Technical guides – Manufacturing Traveler in MES/QMS	Define the digital traveler as the connecting thread for routing, instructions, inspection, serialization, and genealogy.
20	Anebon / Precision AM (2025-26)	Articles – Traceability standards for CNC	Establish traceability levels (lot, heat number, serial) and the role of the traveler in compliance with AS9100 / ISO 9001.

Unit of Analysis

The unit of analysis consisted of the CNC machining area of a manufacturing company dedicated to the production of high-precision metal components. The area has five machining machines, consisting of CNC lathes, vertical and horizontal machining centers, and a wire electrical discharge machining machine, processing an average of 85 production orders per month.

The study considered as its population all production orders executed during the evaluation period. For the statistical analysis, 60 production orders corresponding to the period prior to implementation and 60 orders following the intervention were used, ensuring equivalent conditions for the comparison of results.

Variables and Indicators

The independent variable corresponded to the implementation of a traveler sheet structured under the PDCA methodology, while the dependent variable was the economic and operational impact generated in the CNC machining process.

To evaluate this impact, key performance indicators (KPIs) were defined, selected based on their direct relationship with operational efficiency and production costs.

Table 2. Indicators

Variable	Indicador	Unidad
Document control	Correctly recorded fields	%
Productivity	Cycle time	Hours
Productivity	Information retrieval time	Minutes
Quality	Traceability-related defects	%
Quality	Rework	Events
Production	Setup time	Minutes
Economics	Economic savings	MXN

Table 3. Concepts

Concept	Description
Machine-hour cost	Includes labor, depreciation, and energy
Rework cost	Material, time, and labor
Scrap cost	Material loss
Unproductive time	Minutes converted into economic cost
Monthly savings	Economic benefit obtained
Annual savings	Financial projection
Benefit/Cost	Profitability of the implementation

Information Collection Instruments

During the diagnostic phase, various quality engineering tools were used to identify the main causes of process inefficiency. These included Value Stream Mapping to identify value-added and non-value-added activities; the Ishikawa Diagram to determine the root causes of the problems detected; and Pareto Analysis, applied to 156 nonconformity reports for the purpose of identifying the causes responsible for the highest percentage of defects and delays.

As the main intervention instrument, the HV-CNC-001 traveler sheet was designed, consisting of six sections: lot identification, sequence of operations, quality control, material traceability, logistics monitoring, and product release. Additionally, three Standard Operating Procedures (SOPs) were developed to ensure the proper application of the tool and standardize the activities of operational personnel.

Table 4. Tools

Tool	Objective
Value Stream Mapping	Identify value-added and non-value-added activities
Ishikawa Diagram	Determine root causes
Pareto Analysis	Prioritize the causes with the greatest impact
HV-CNC-001 Traveler Sheet	Document control and traceability
Standard Operating Procedures	Standardize activities
KPI Indicators	Evaluate performance

Procedure

During the **Plan** phase, the process was diagnosed through direct observation, document analysis, and the application of quality tools. Subsequently, the main causes of waste were identified, and the traveler sheet was designed considering the operational requirements of the area.

During the **Do** phase, the traveler sheet was initially implemented through a pilot program accompanied by training for operational personnel. Subsequently, the tool was extended to the remaining workstations once the adjustments derived from the trial period had been validated.

During the **Check** phase, the performance indicators defined for the research were monitored, comparing the results obtained before and after implementation in order to evaluate the effectiveness of the intervention.

Finally, during the **Act** phase, the procedures derived from the project were standardized, incorporating the traveler sheet into the organization's document management system and establishing improvement actions aimed at strengthening process continuity, including proposals for digitalization and integration with production planning and control systems.

Table 5. Stages

Stage	Activities Performed	Expected Result
Plan	Diagnosis, Pareto, Ishikawa, VSM, and traveler sheet design	Identification of root causes
Do	Training and pilot implementation	Start of traveler sheet use
Check	Indicator monitoring	Measurement of results
Act	Standardization and improvement actions	Process consolidation

Statistical and Economic Analysis

The statistical analysis was conducted using pre- and post-intervention comparison tests. For continuous variables, the Student's t-test for paired samples was used, while for variables that did not meet the assumptions of normality, the Wilcoxon signed-rank test was used, considering a significance level of $p < 0.05$.

In parallel, a cost-benefit economic analysis was developed, translating the improvements obtained in the operational indicators into monetary terms. For this purpose, the average machine-hour cost, the cost associated with rework and materials, as well as the average monthly production volume were considered. Based on these parameters, the monthly and annual savings generated by the implementation of the traveler sheet were estimated, allowing the economic feasibility of the intervention to be evaluated and the financial impact derived from process improvement to be quantified.

Table 6. Indicator Validation

Indicator	Baseline	Target	Result
Information retrieval time	8.4 min	≤5 min	4.2 min
Traceability defects	4.8 %	≤3.4 %	2.9 %
Cycle time	72 h	≤61.2 h	58.5 h
Rework	14.3	≤10	7.8
Setup	38.2 min	≤30 min	27.4 min

RESULTS OR FINDINGS

All indicators exceeded the targets established in the research hypothesis. The pre- and post-implementation comparative results are presented in the following Table.

Table 7. Indicator Results

INDICATOR (KPI)	BASELINE	OBJECTIVE	RESULT	VARIATION
Information retrieval time (min/event)	8.4	≤5.0 (−40%)	**4.2**	**−50.0%**
Traceability-related defects (%)	4.8%	≤3.4% (−30%)	**2.9%**	**−39.6%**
Total cycle time (h/order)	72.0	≤61.2 (−15%)	**58.5**	**−18.8%**
Rework due to specification (events/month)	14.3	≤10.0 (−30%)	**7.8**	**−45.5%**
Correct fields in traveler sheet (%)	N/A	≥85%	**93.7%**	**+93.7%**
Setup time (min)	38.2	≤30.0 (−21%)	**27.4**	**−28.3%**

The statistical tests applied ($p < 0.05$ in all cases) confirm that the improvements are statistically significant and not attributable to chance. The most notable improvements were recorded in the reduction of rework due to specification errors (−45.5%), the reduction in information retrieval time (−50.0%), and the reduction in internal defects attributable to traceability problems (−39.6%).

Economic Impact Evaluation

With the objective of quantifying the financial benefit of implementing the traveler sheet (HV-CNC-001), a cost-benefit analysis was conducted by translating the percentage improvements in the KPIs into tangible economic savings.

For this calculation, a base economic scenario representative of the operations of Carviflon S.A. de C.V. was established, considering an average machine-hour cost of $600 MXN (which includes operator labor, equipment amortization, and energy consumption) and an estimated material and rework cost of $2,500 MXN per event.

Based on a monthly volume of 85 production orders, the projected monthly and annualized economic savings were determined for the four operational indicators with the greatest impact, the results of which are summarized in the following Table.

Table 8. Economic Impact Report

IMPACTED INDICATOR	PERCENTAGE IMPROVEMENT	MONTHLY SAVINGS	PROJECTED ANNUAL SAVINGS
Information retrieval time	-50.0%	$14,280 MXN	$171,360 MXN
Traceability-related defects (Scrap)	-39.6%	$19,200 MXN	$230,400 MXN
Rework due to specification	-45.5%	$16,250 MXN	$195,000 MXN
Setup Time (Released Capacity)	-28.3%	$9,180 MXN	$110,160 MXN
TOTAL ESTIMATED SAVINGS		**$58,910 MXN**	**$706,920 MXN**

PHASE 4 – ACT

The Act phase corresponds to the standardization, consolidation, and continuous improvement planning activities developed during the final month of the project. Since the results of the Check phase confirmed compliance with all the objectives established, the course of action adopted was the standardization of the traveler sheet as part of the production management system of Carviflon S.A. de C.V. The standardization activities carried out during the Act phase included:

a) Update of the Document Management System: The traveler sheet was formally incorporated into the company's document management system, assigning it document code HV-CNC-001 and establishing a revision control procedure to ensure its periodic updating in accordance with changes in the products or processes of the area.
b) Review and update of standard operating procedures: The three SOPs developed during the preparation phase were reviewed in light of the lessons learned during the implementation and verification period, incorporating the additional clarifications and examples that proved necessary during the adoption of the document.
c) Integration with the production planning system: A procedure was established for the planning area to automatically generate the identification and sequence-of-operations sections of the traveler sheet from the production order in the company's ERP system, reducing document preparation time and the risk of transcription errors.
d) Induction training for new employees: A module on the use of the traveler sheet was incorporated into the induction program for newly hired personnel in the CNC machining area, ensuring that all operators know and can correctly use the document from the beginning of their activities.

The analysis of the incidents recorded during implementation and the data from the verification phase made it possible to identify the following improvement opportunities:

Table 9. Improvement

IMPROVEMENT OPPORTUNITY	DESCRIPTION OF THE IDENTIFIED OPPORTUNITY
Digitalization of the traveler sheet	68% of the personnel interviewed expressed interest in implementing a digital version of the traveler sheet accessible from tablets or terminals installed at the machines.
Integration with the dimensional inspection system	The possibility of linking the dimensional measurement results recorded in the traveler sheet with the software of the coordinate measuring machine (CMM) in the metrology laboratory was identified, automating the comparison between measured values and nominal specifications.
Extension to other areas of the company	The positive results obtained in the CNC machining area generated interest in the heat treatment and surface finishing areas, whose managers requested an evaluation of the feasibility of implementing traveler sheets adapted to their specific processes.
Incorporation of sustainability indicators	It is proposed to add fields to record coolant consumption and metal chip generation per production order, with the purpose of developing indicators for energy efficiency and waste management.

Based on the analysis of the 23 incidents recorded during the pilot and the observations from the verification period, the following corrective and preventive actions (CAPA) were defined and documented for implementation in the next improvement cycle:

a) Corrective Action 1: Redesign of the CNC program code field in the traveler sheet, which was the field with the highest number of filling errors (38% of total errors), incorporating a predefined drop-down list for the digital version and a verification color code for the printed version.
b) Corrective Action 2: Establishment of a weekly audit routine for traveler sheets in process, carried out by the quality inspector on duty, to detect and correct filling errors before the order advances to the next stage of the process.
c) Preventive Action 1: Incorporation of a quarterly refresher module on the use of the traveler sheet into the area's continuous training program, in order to maintain filling quality in the long term and reinforce the documentation culture among newly hired personnel.
d) Preventive Action 2: Semiannual review of the traveler sheet format by a committee consisting of the area manager, the quality manager, and two representative operators, to ensure that the document remains relevant in the face of changes in products, processes, or applicable quality standards.

CONCLUSIONS

The implementation of a traveler sheet based on the Plan–Do–Check–Act (PDCA) cycle made it possible to strengthen production control in the CNC machining area, improving the traceability of manufacturing orders and standardizing the recording of information throughout the production process. This contributed to reducing the main causes of inefficiency identified during the initial diagnosis.

The results obtained showed a reduction in information retrieval times, rework, traceability-related defects, and machine setup times, which was reflected in greater productivity and better utilization of resources. These improvements demonstrate that process standardization is an effective tool for increasing operational efficiency.

From an economic perspective, the research confirmed that the implementation of the traveler sheet had a direct impact on reducing operating costs by decreasing activities that did not add value to the process. The savings obtained, estimated at $706,920 MXN annually, demonstrate that continuous improvement also represents a financial benefit for organizations by optimizing the use of resources and reducing losses resulting from rework, unproductive time, and documentation errors.

Finally, this research demonstrates that the application of the PDCA cycle, supported by a document control tool such as the traveler sheet, not only improves operational performance but also generates measurable economic benefits. Therefore, its implementation represents a viable alternative for manufacturing companies seeking to strengthen their competitiveness, reduce costs, and improve decision-making through standardized processes oriented toward continuous improvement.

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