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A STRUCTURED CONTINUOUS IMPROVEMENT PROCESS FOR HIGH-RISE CONSTRUCTION USING TIME-MOTION STUDIES

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ABSTRACT

This research investigates the implementation of a pragmatic continuous improvement process following a PDCA (Plan-Do-Check-Act) cycle within a large Mexican construction company specializing in post-tensioned concrete for high-rise buildings. Over a 2.5-year period and across 13 active projects ranging from 20 to 50 stories, the company aimed to optimize slab construction cycles, a critical and repetitive element impacting project duration and cost. To bridge the gap between field-level innovation and organizational implementation, this research presented a structured four-step PDCA approach: Step 1 - Plan: Time-motion study review and collaborative brainstorming; Step 2 - Do: Controlled trial implementation; Step 3 – Check: Data collection and evaluation; and Step 4 – Act: Standardization via A3. Over 200 time-motion studies, primarily on rebar and formwork (97%), provided data-driven insights that led to the development of 205 improvement initiatives, with 175 approved for trial implementation. Among these, 88 % targeted time, cost, and quality improvements. While the PDCA process proved effective in driving operational efficiency, challenges persist in sustaining momentum, enhancing communication channels, and reducing reliance on manual data processing. This study highlights the role of a structured bottom-up approach in integrating field-level innovation into long-term organizational improvements in construction projects.

KEYWORDS

Continuous Improvement, Time motion studies, PDCA, Kaizen, A3.

INTRODUCTION

Continuous improvement lies at the core of lean implementation, serving as a pivotal strategy for organizations aiming to enhance outcomes, including safety, quality, and productivity (Stevens at al., 2023). At its essence, continuous improvement embodies the principle of *kaizen*, which emphasizes ongoing incremental improvement through the active involvement of all team members, including managers and workers within the production system (Vieira et al., 2018). To ensure these efforts are systematic and sustainable, organizations integrate the PDCA (Plan-Do-Check-Act) method, a structured cycle that facilitates the identification, implementation, evaluation, and standardization of improvements (Shaibh & Parrish, 2024).

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Previous research highlights the role of continuous improvement cells as small-group mechanisms that bring the *kaizen* principle to life. Continuous improvement cells intersect with continuous improvement, visual management, and policy deployment (Tezel et al., 2018). However, challenges persist in deploying continuous improvement strategies effectively across projects and scaling these efforts to achieve broader organizational impact. The ability to capture learning from localized initiatives and implement them on a larger scale remains an ongoing ambition for many organizations.

Despite the promise of continuous improvement methodologies, there is a notable lack of empirical evidence demonstrating their effectiveness, with only a few studies presenting evidence of performance improvement in production rates and labour productivity for the structural frame construction of high-rise buildings (Verán-Leigh et al. 2022; Cossio et al. 2024). This gap in evidence extends to applying *kaizen*, PDCA, and A3 problem-solving techniques, which are widely recognized in manufacturing but less thoroughly documented in high-rise construction. Furthermore, the construction industry needs a structured process to guide organizations in translating field-level innovations into standardized practices for long-term adoption. While individual projects may generate valuable improvements and innovations, the lack of a systematic approach to capture, evaluate, and disseminate these learnings across the organization often results in missed opportunities for broader implementation and sustained benefits.

To address these gaps and challenges, this research aims to develop a continuous improvement strategy to bridge time-motion studies data (field-level innovation) with overall performance improvement metrics (organizational implementation). To achieve this aim, this study examines the application of a continuous improvement strategy based on the PDCA cycle within a large construction company in Mexico, focusing on the structural frame construction phase, with the specific goal of reducing slab cycle time and increasing quality. The study demonstrates a top-down collaborative approach to implementing small-scale improvement initiatives that yield broader project-level benefits. This case provides evidence of how targeted continuous improvement strategies can address project-specific challenges while contributing to broader operational excellence by optimizing program efficiency and improving productivity.

BACKGROUND

CONTINUOUS IMPROVEMENT

The principle of continuous improvement is central to the success of practical implementations of lean construction, which encourages teams to constantly evaluate and refine their processes for better long-term outcomes (Stevens et al. 2023). The concept of *kaizen*, or continuous improvement, emphasizes structured, data-driven problem-solving to foster a culture of ongoing performance improvement. According to Vieira et al. (2018), the effective implementation of *kaizen* requires a systematic, eight-step approach: (1) selecting a focus aligned with organizational priorities; (2) analyzing the context; (3) collecting and analyzing data to identify root causes; (4) establishing countermeasures based on data; (5) implementing the countermeasures; (6) confirming their effects; (7) revising standards to prevent recurrence; and (8) reviewing and initiating subsequent improvement steps. This structured approach ties directly to the PDCA (Plan-Do-Check-Act) cycle, which enables stakeholders to test potential changes on a small scale and assess their impact before committing to a larger investment in the change (Shaibh & Parrish, 2024). The PDCA cycle supports *kaizen* by promoting continuous testing and refinement, ensuring that improvements are grounded in real data and that results are standardized across the organization.

In construction, continuous improvement principles have been applied through various lenses. Ahonen et al. (2022) explored takt production as a process model for continuous improvement, emphasizing flow efficiency. Robert and Granja (2006) demonstrated that combining target costing with *kaizen* led to a 13% improvement in cost efficiency by leveraging production process analyses and subcontractor input. This highlights how *kaizen* principles, combined with structured methods like PDCA, can substantially improve construction efficiency. Stevens et al. (2023) showed the potential of *kaizen* in infrastructure projects, reporting significant cost savings achieved through targeted interventions.

The integration of A3 problem-solving into *kaizen* further enhances decision-making and knowledge retention. Bordin et al. (2018) investigated the use of A3 reports to accelerate decision-making and improve collaboration among management and workers, reducing lead times in steel manufacturing processes. A3's structured documentation process aligns with the PDCA cycle, supporting the identification of problems, root causes, and solutions in a systematic manner. Vieira et al. (2018) reported the benefits of kaizen in concrete wall construction for social housing projects, demonstrating a 14%–36% reduction in lead times through process stabilization and team restructuring. In sum, *kaizen* is a broad improvement philosophy, while PDCA provides a structured way to test and implement changes. A3 problem-solving helps document and communicate solutions and ensures successful improvements become part of routine operations.

However, despite these successes, capturing granular field data and documenting performance improvement remains crucial for sustaining continuous improvement efforts. Time-motion studies and site observations are practical tools for identifying improvement opportunities, ensuring that *kaizen* initiatives are grounded in actionable insights. When integrated into the PDCA and A3 methodologies, these tools ensure that improvements are based on objective, data-driven evidence, supporting sustainable organizational change.

TIME-MOTION STUDIES

Time-motion studies are critical tools in lean construction, aimed at identifying inefficiencies, optimizing productivity, and improving workflow in construction processes (Demirkesen et al., 2020). These studies involve the systematic observation of work systems to analyze activities, reduce waste, and standardize effective methods. Thomas et al. (1990) described time and motion studies as a method for finding and implementing least-cost approaches, determining standard times, and assisting in training workers in preferred practices.

Kalsaas et al. (2022) applied observational methods that analyze dimensions such as smoothness, quality, and intensity, providing valuable insights into how time is utilized at construction sites. This approach helps measure workflow and identify waste, contributing significantly to production planning. For instance, understanding how time is spent, and workflows are organized can improve coordination, detect inefficiencies, and streamline operations in complex projects. Seppänen and Görsch (2022) investigated waste reduction in Mechanical, Electrical, and Plumbing (MEP) work. Their study revealed that direct work accounted for just 25% of electricians' time and 15% of plumbers' time. The primary causes of wasted effort included poor communication, uncoordinated designs, inadequate material flow, and high levels of preparatory work. Additionally, they emphasized the importance of improving design constructability, which could enable just-in-time logistics and increase prefabrication, thereby reducing waste.

Time-motion studies are a foundational tool for initiating continuous improvement efforts in construction. By identifying the root causes of inefficiencies at the activity level, these studies offer actionable insights to minimize waste, enhance productivity, and promote the broader adoption of lean practices, ultimately driving performance improvement. However, there is a notable gap in research addressing the structural frame of high-rise construction. This area presents unique learning opportunities, as lessons gained from executing lower levels can be systematically applied to improve efficiency and effectiveness in the upper levels, leveraging the iterative nature of such projects.

METHOD

This research implemented and documented the PDCA cycle in line with previous studies (Murata, 2023; Shaibh & Parrish, 2024). This study presents the case of a Mexican construction organization with over 40 years of national operational experience and a substantial portfolio exceeding 20 million square meters of built area. This organization specializes in designing and constructing post-tensioned concrete structures for high-rise developments. Having embarked on its lean journey over a decade ago, the firm has progressively integrated lean principles into its project delivery processes. Over the past two years, the company has intensified its focus on detailed process analysis and improvement, recognizing the crucial role of optimized workflows in achieving project success. Implementing the Last Planner System (LPS) and other lean tools and techniques such as Value Stream Mapping, 5S, and Just in Time has become integral to project execution, establishing a strategic advantage in a competitive market.

This research specifically investigates the company's recent and focused efforts to analyze and optimize the individual processes comprising each slab construction cycle using continuous improvement methodologies like PDCA and A3. The slab cycle is a critical and repetitive element in high-rise construction, and its efficiency directly impacts overall project duration and labor productivity as presented in a previous study (Cossio et al., 2024).

Over a 2.5-year implementation period, external lean consultants, engaged by the contractor, conducted over 200 time-motion studies to analyze key repetitive activities within the concrete slab cycle across 13 projects within the same company. These projects were developed in different locations in Mexico and encompassed the construction of post-tensioned concrete structures mostly for residential purposes ranging from 20 to 50 stories in height. The consultants performed all the time-motion studies using direct observation and video recording. Using time-motion software, video recordings were subsequently analyzed to facilitate measurement and activity categorization. Practical experience demonstrated that video recording was most effective for operations lasting up to 45 minutes or involving teams of more than two people. Direct observation was preferred for more prolonged operations. Data from the observations and studies were recorded in a spreadsheet, documenting the participating workforce, a step-by-step process breakdown, the time spent on each activity, supporting images, and relevant observations. The studies focused on key post-tensioned concrete construction activities: rebar installation, formwork, concrete placement, and tension rod installation.

PROPOSED CONTINUOUS IMPROVEMENT PROCESS

Initial attempts to implement efficiency improvements, driven by the detailed analysis of time-motion studies by proactive site engineers and crew leaders, revealed a critical need for structured organizational support. While these field-based teams demonstrated a clear capacity for identifying and developing innovative and practical solutions, many promising initiatives struggled to achieve their full potential due to a lack of consistent follow-through, standardized implementation processes, and company-wide adoption. This experience highlighted a significant gap between field-level innovation and organizational implementation, underscoring the importance of implementing a process to bridge this divide. Without a standard process, valuable insights and potential efficiency gains risked being lost, hindering overall project performance and organizational learning. This realization led to the development of a formal process specifically designed to facilitate the successful implementation and scaling of field-driven improvements as presented in Figure 1.

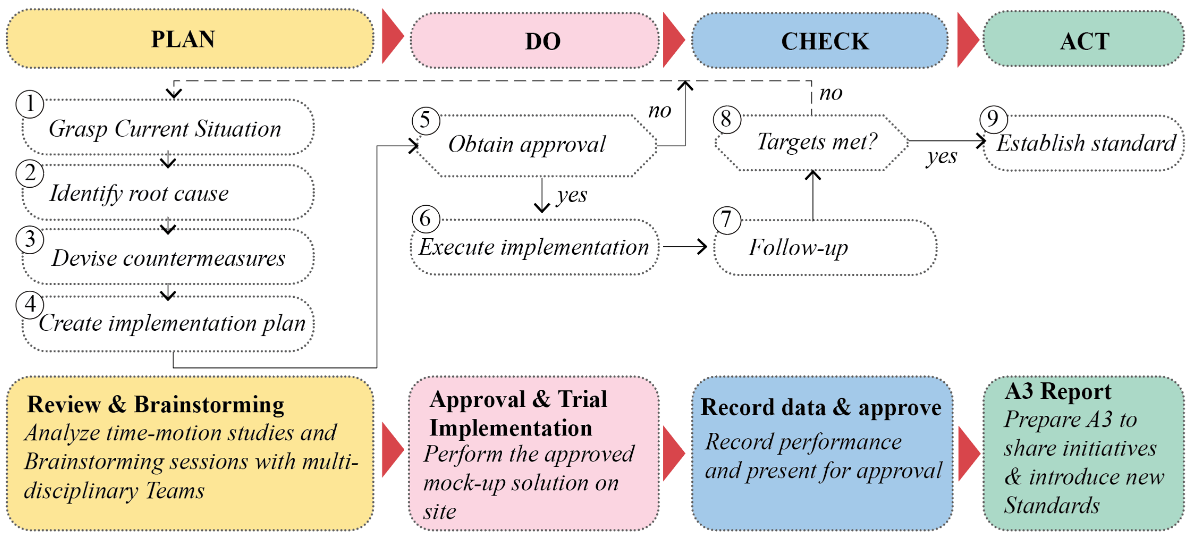

Figure 1: Continuous Improvement Implementation Process

The following sections describe how the practical application of a PDCA cycle was developed across 13 concurrent projects. The implementation process that was followed during these projects consisted of four distinct steps:

Step 1 - Plan: Time-motion study review and collaborative brainstorming

A dedicated team of site engineers and consultants conducted systematic reviews of existing time-motion studies and direct field observations every week. This approach prioritized critical operations within the slab cycle - those exhibiting longer durations, higher variability, or presenting significant challenges in execution. The goal of these reviews was not simply to identify problems but to pinpoint specific opportunities for improvement. Each review session culminated in selecting a single, focused improvement opportunity to be discussed by the broader project team. This focused approach ensured that efforts were concentrated on addressing the most impactful areas. Once the initiative was selected, the consultant prepared information (photographs, drawings, videos) to be presented in the next step.

The selected improvement initiative was then presented to a cross-functional team of foremen representing all construction activities (e.g., formwork, rebar, concrete placement), engineering leaders and project managers. This diverse team composition ensured various perspectives and practical insights were brought to analyze the problem. A structured brainstorming session was conducted, employing techniques such as cause-and-effect diagrams (Ishikawa diagrams) or 5 Whys analysis to thoroughly explore the root causes of the identified issue and generate potential solutions.

The main objectives of these sessions were to validate with the team the feasibility and impact of the initiative selected and to gather sufficient information to develop a comprehensive proposal for review by upper management. This proposal included a detailed assessment of the anticipated benefits of the proposed solution (e.g., reduced cycle time, decreased material waste, improved safety), a cost analysis, and an estimated timeframe for implementation.

Step 2 - Do: Controlled trial implementation

Site engineers and project managers meticulously compiled the information gathered during the brainstorming sessions into a formal presentation for review by top management. These presentations were integrated into the weekly project progress meetings, ensuring that improvement initiatives were given appropriate visibility and attention. During these presentations, the team presented the problem addressed, the proposed solution, the expected benefits, the associated costs, and the proposed implementation plan.

Based on the estimated implementation costs and potential benefits, management made one of three decisions: approval, a request for further development, or rejection. This formal review process ensured all proposed changes were carefully aligned with project strategic goals. Upon receiving management approval, the team proceeded with a controlled trial implementation, or mock-up, of the proposed solution in a specific area or under controlled conditions. This approach minimized disruption to ongoing project activities while allowing for testing and data collection.

Step 3 – Check: Data collection and evaluation

The implementation process was meticulously documented during the trial, including details of the methods used, resources required, and any unexpected challenges encountered. Furthermore, the team collected data on key performance indicators (KPIs) relevant to the initiative, such as cycle time, resource utilization, defect rates and safety. This data collection provided objective evidence of the solution's effectiveness and allowed for a quantitative assessment of its impact.

Step 4 – Act: Standardization via A3

Following the trial implementation, the team synthesized the collected data, documented the entire process, observed results, and realized benefits in an A3 report. This standardized reporting format facilitated clear communication of the initiative's key aspects. The A3 report explicitly highlighted the potential benefits of permanently incorporating the initiative into the standard slab cycle process, emphasizing the positive impact on project performance. Upon management approval, the initiative was officially integrated into the Project's standard operating procedures, ensuring that the improvements were sustained and replicated across subsequent slab cycles or to other projects with similar characteristics. This standardization process solidified the gains achieved through the improvement initiative and contributed to continuous improvement within the company.

IMPLEMENTATION RESULTS

STEP 1 - PLAN: TIME-MOTION STUDY REVIEW AND COLLABORATIVE BRAINSTORMING

Each time-motion study summarized observed work time as value-added (rebar installation, formwork installation, concrete pouring), non-value-added (waiting time, reworks), or support activities (scaffoldings, safety prep work). These studies revealed an average of 59% of time spent on value-added tasks, with the remaining 41% dedicated to support and non-value-added activities (Figure 2). It is crucial to note that these percentages reflect observations of small crews (2-4 operatives) working as a unit. This aggregation may inflate the reported value-added time, as the studies focused solely on active work crews, excluding broader project personnel. Furthermore, the presence of observers likely influenced worker behavior, potentially leading to a Hawthorne effect and skewing results. Despite these limitations, the substantial 41% allocated to non-value-added and support activities suggests considerable potential for process optimization.

These studies proved invaluable in generating data-driven insights and fostering ideas for targeted improvement initiatives. By systematically observing and recording the time taken to perform specific tasks, these studies provided a granular understanding of workflow inefficiencies and areas for potential optimization. Given the substantial time investment associated with rebar and formwork, these two activities, which contribute most significantly to overall project duration, were prioritized, accounting for 97% of the studies.

Time-motion studies were made accessible company-wide, enabling all projects to benefit from this resource, regardless of where the original study was conducted. This centralized repository of time-motion data facilitated knowledge sharing and cross-project learning.

Figure 2: Category of activities observed during time motion studies

Continuous improvement initiatives

Analysis of the 205 improvement initiatives generated by the 13 participating projects revealed an uneven distribution across projects, suggesting influencing factors beyond the continuous improvement process itself. Two primary factors appear to drive the variation in the number of initiatives developed: the number of time-motion studies conducted and the project manager's leadership and engagement. As shown in Figure 5, a disproportionate share (69%) of the initiatives originated from just five projects, which also accounted for 72% of the total time-motion studies. This strong correlation underscores the importance of data-driven analysis, particularly in the Plan phase of the PDCA cycle, to clearly define the problem and its root cause. The availability of detailed time-motion data appears to be a crucial catalyst for generating ideas for improvement.

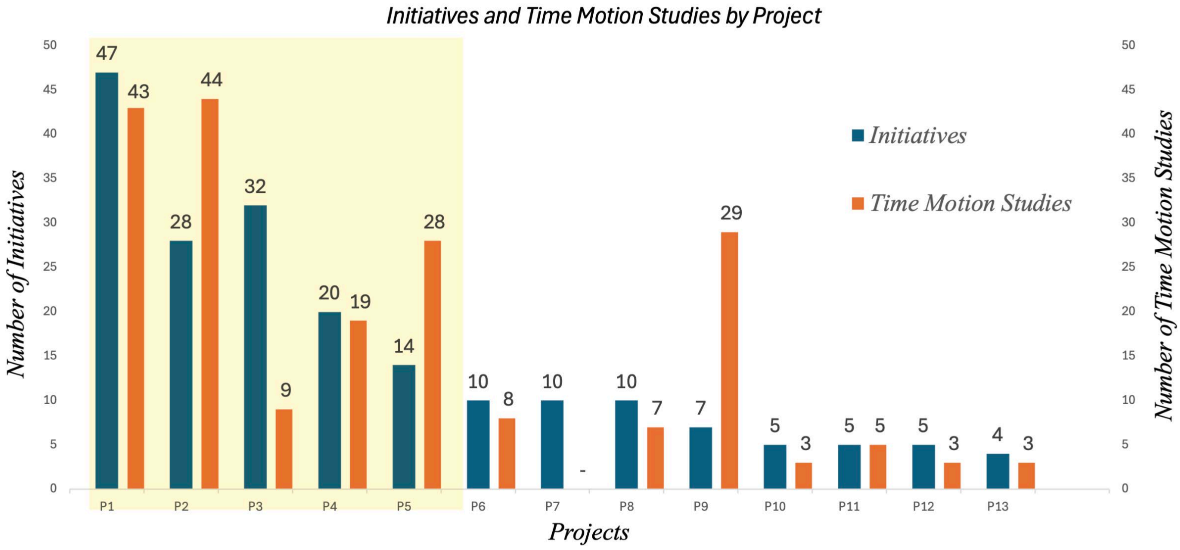

Figure 5: Number of initiatives and Time Motion studies by Project

However, the data also suggests that data alone is insufficient. The contrasting experiences of Projects P3 and P9 highlight the critical role of project leadership in translating data into action. P3, despite having fewer time-motion studies (9) than some other projects, generated a substantial number of initiatives (22). This success can be attributed to the project manager's strong commitment to the continuous improvement process and their active encouragement of team participation. Conversely, P9, despite benefiting from a significant number of time-motion studies (29), produced comparatively few initiatives (7). This relative lack of output can be attributed to the project manager's apparent lack of engagement and support for the implementation process. This demonstrates that even with robust data, effective leadership is essential to drive the translation of insights into tangible improvements. Without active leadership, the potential benefits of time-motion studies and the continuous improvement process may not be fully realized.

The initiatives developed fall into four primary categories: time and cost, quality, safety and order, and material logistics. *A strong emphasis was placed on time/cost and quality initiatives, comprising 88% of all submitted initiatives* (Figure 6). This prioritization reflects the company's focus on improving efficiency and delivering high-quality projects, directly informed by the insights gained from the time-motion studies.

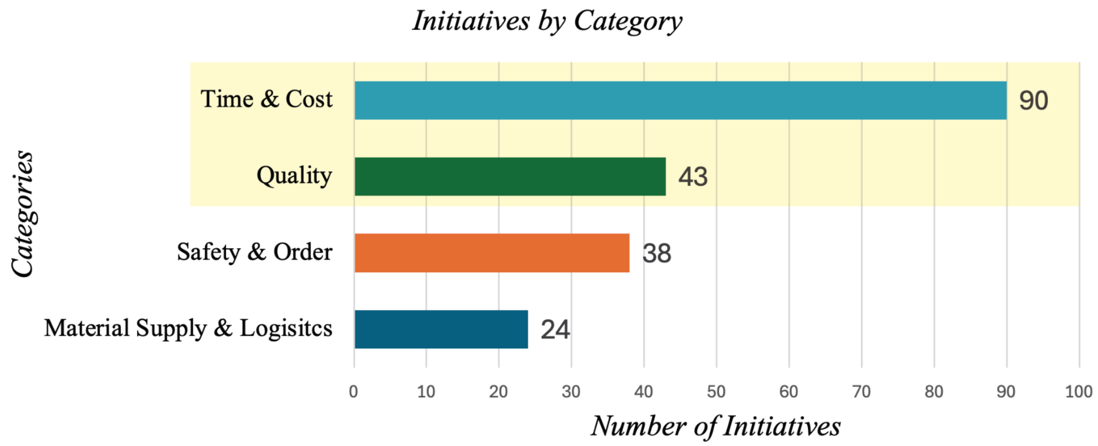

Figure 6: Initiatives developed by category

Step 2 - Do: Controlled Trial Implementation

Management approved 175 of the 205 developed initiatives (85%) for field trials and mock-ups. This high approval rate suggests that the initiatives were well-aligned with the company's objectives and addressed significant operational challenges identified through the time-motion studies. Project P3, among the 13 projects, demonstrated accelerated implementation of improvement initiatives driven by strong project management leadership. Of the 32 initial proposals, 7 (22%) were deemed infeasible and discarded, leaving 25 initiatives to proceed to the trial and data collection phase. Examples of the trials implemented include:

- *Improved Column Falsework* (Figure 3): As documented by the time-motion studies, the previous formwork procedure required excessive carpentry time and resulted in high wood consumption. The new procedure, utilizing cylindrical formwork, directly addressed these inefficiencies. This change achieved a *55% reduction in time*, eliminated rework due to concrete leakage (a source of significant downtime identified in the studies), and reduced wood consumption.

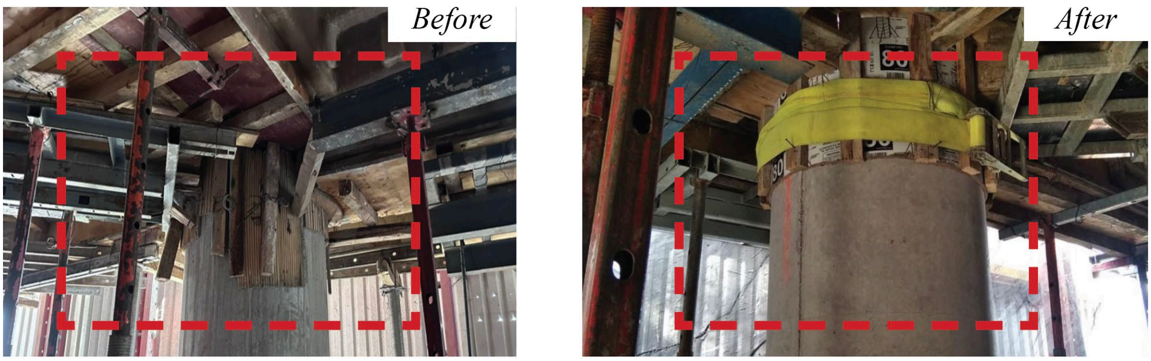

Figure 3: Improvement of falsework and formwork for column

- *Falsework Layouts and Color Coding (Figure 4a*): Time-motion studies revealed that frequent floor-to-floor transitions of falsework components resulted in wasted time due to searching for parts and inefficient movement. Implementing standardized layouts and color coding for falsework components directly addressed this issue, minimizing unnecessary movement during floor-to-floor transitions. This also reduced labor hours for subsequent formwork assembly and decreased the need for additional materials.
- *Falsework Guides for Concrete Topping Level (Figure 4b):* The studies highlighted inconsistencies in concrete topping levels, leading to rework and delays. Carpenters implemented markings on the falsework indicating the concrete topping level and installed guides along the perimeter. This facilitated concrete finishing and improved levelling accuracy, thereby reducing rework identified in the time-motion studies.

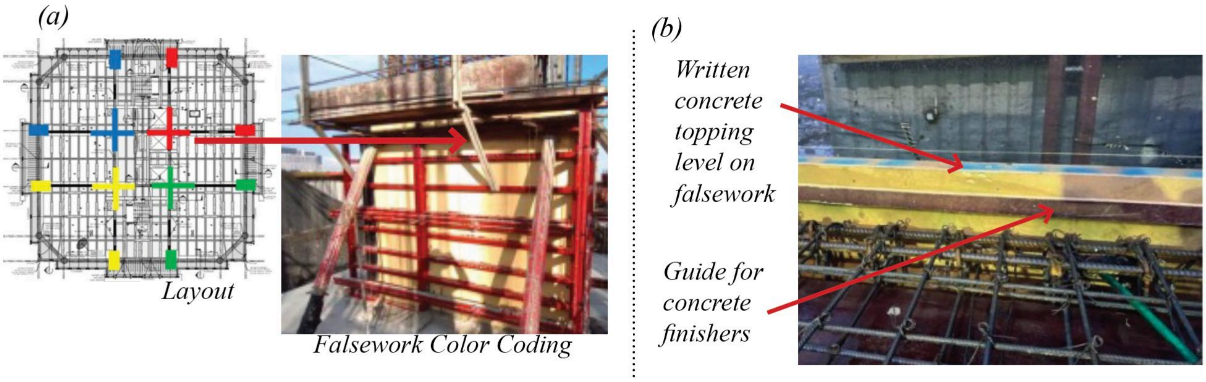

Figure 4a and Figure 4b: Color coding for falsework and guides on falsework

- *Concrete maturity sensors in columns:* The implementation of concrete maturity sensors proved beneficial in situations where formwork availability was limited. By providing real-time data on concrete strength development, these sensors enabled carpenters to remove formwork earlier than traditional methods allowed safely. This accelerated the construction cycle by allowing the formwork to be reused in the next batch of columns, optimizing resource utilization.

Step 3 – Check: Data Collection and Evaluation

This step focuses on the results from Project P3. Performance data from other projects was unavailable at the time of writing, as most of these projects were in their trial phase and data was not yet sufficiently developed. Therefore, this report is limited in its comparative analysis with other projects. Future iterations of this research will include more extensive data from these additional projects. As illustrated in Figure 7, Project P3's weekly production index (m^3/100 worker-hours) demonstrated a significant increase following the implementation of initiatives derived from the PDCA process. Before implementation, the average productivity index was 1.13 m^3/100 worker-hours. After implementation, this index rose to 3.43 m^3/100 worker-hours, marking a substantial improvement of 202%. While some performance dips are evident in week 39 (due to tower crane availability issues) and week 52 (due to the Easter holidays), the overall upward trend in productivity is clearly visible.

Step 4 – Act: Standardization Via A3

Project P3 is currently the only Project to advance to step 4, standardization using A3. Following the tryouts and selection processes of steps 2 and 3, 22 of the original 32 initiatives (68%) were documented in A3 reports for standardization. These A3 reports, which are concise one-page documents used to summarize problems, analyses, and action plans, were elaborated by the consultants in collaboration with the project management team. An example of the A3 report document is shown in Figure 8.

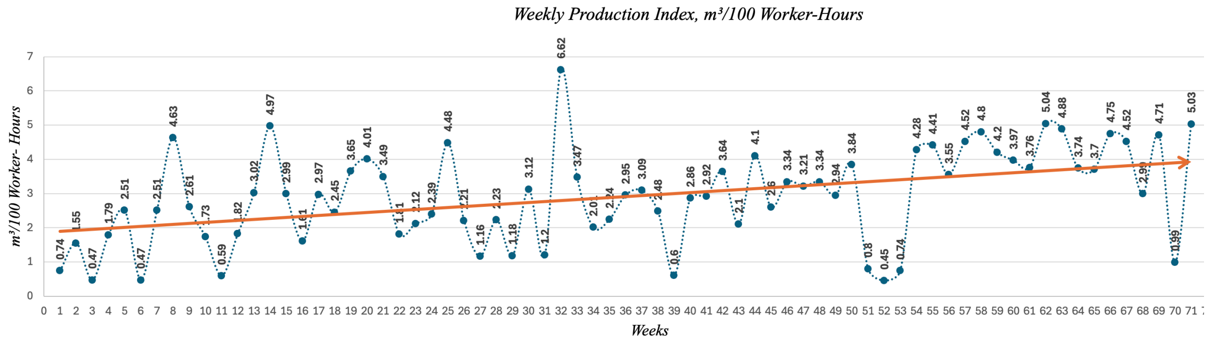

Figure 7: P3 performance index by week

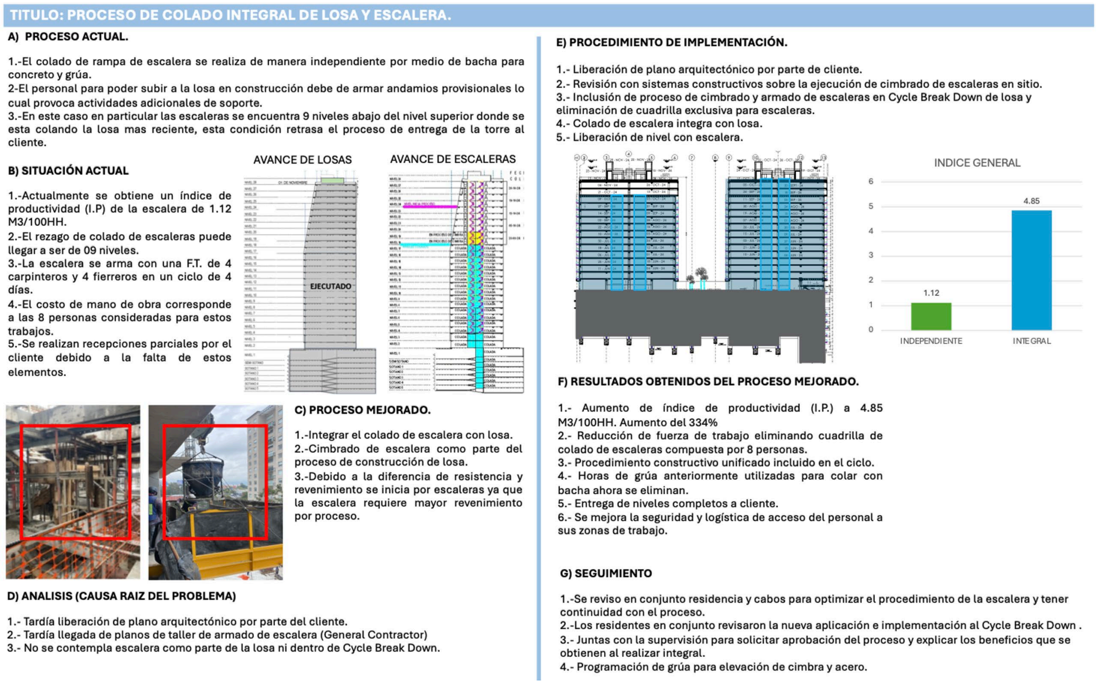

Figure 8: A3 report for standardization example

DISCUSSION AND CONCLUSION

The implementation process revealed several challenges requiring ongoing attention. Maintaining momentum and ensuring the sustained application of the continuous improvement process remains a key concern. This necessitates a consistent flow of data, particularly from time-motion studies, which proved crucial to identify improvement opportunities and objectively measure the impact of the implemented changes. Meticulous tracking of initiatives throughout the trial and standardization phases is also essential to ensure that improvements are effectively embedded into standard operating procedures.

The current process's dependence on project manager engagement and team participation is a further challenge. Beyond the quantifiable performance gains, project leaders commented on a positive impact on team morale due to participation in the continuous improvement process, which provided team members with a platform to be heard and offered opportunities for creative problem-solving, breaking the monotony of daily routines. While the improvements easing daily operations and increasing job site safety have driven current participation, an incentive program incorporating additional compensation and recognition could further motivate and sustain team engagement. Future steps will need to address how this incentive program can be implemented.

While Project P3's performance results demonstrated the positive impact of the practical PDCA implementation presented in the case study, further data from the rest of the projects is needed to validate this approach's effectiveness and broader applicability fully. In future steps, we expect to have performance indexes from all the projects involved in the implementation to better understand the correlation between time-motion studies, improvement initiatives, and overall performance. Effective communication and knowledge management also presented a challenge. Establishing a robust platform for disseminating new processes derived from time-motion study insights to the entire team and creating an accessible archive for new members is crucial. Such a platform would ensure consistent knowledge transfer and prevent reliance on informal communication or individual memory.

This study has some limitations. Manual activity categorization in time-motion studies is time-consuming and resource-intensive, presenting an opportunity for using computer vision and machine learning to automate activity identification and classification from video recordings, significantly reducing analysis time. AI could also uncover subtle inefficiencies missed by human observers, leading to more effective improvements. Developing internal AI expertise will further empower proactive identification and resolution of inefficiencies, ensuring a data-driven continuous improvement process.

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