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Original Article

Lean-TPM Approach to Improve Delivery Compliance and Downtime Reduction in a Peruvian Microenterprise: A Transport Sector Case Study

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Abstract -*. Peru's micro and small transport enterprises face persistent operational inefficiencies, often worsened by limited access to structured improvement methodologies. Previous studies have demonstrated the effectiveness of Lean Manufacturing and TPM tools in larger industrial settings, but their adaptation to small-scale services remains underexplored. Through a tailored improvement model, this study addressed the challenge of low delivery compliance and excessive downtime in a microenterprise. The proposal integrated 5S, Autonomous Maintenance, and SMED, implemented over five months. The actions focused on standardization, technical inspections, and changeover time reduction. Results showed an increase in delivery compliance from 58% to 90%, a 60.69% reduction in component changeover time, and an improvement in machine inspection rates from 33% to 83%. These advances contributed to greater service reliability and operational continuity. The findings reveal the viability of Lean-TPM applications in constrained environments. Future research is encouraged to replicate and extend this model in diverse contexts to strengthen its impact.*

Keywords – *Lean Manufacturing, Total Productive Maintenance, Delivery Compliance, Transport Sector, Operational Efficiency.*

1. Introduction

Small and medium-sized enterprises (SMEs) in transportation function as the connective tissue of the global economy, linking distant production sites to urban marketplaces [1]. Their footprint extends beyond trucks and railcars; these firms generate millions of jobs while smoothing the daily flow of freight and passengers, a benefit recorded in both developing and industrialized settings [2].

Latin America illustrates the trend nicely: booming foreign trade and upgraded warehouse corridors have lifted the transport SME segment, even though old problems like a fragmented market, high informality, and lagging technology still cling to the industry [3].

Peru tells a more focused story. Here, more than 96 percent of all transport firms qualify as SMEs, and they carry most of the country’s cargo and passengers through a mountain-and-jungle maze where paved roads often disappear [4]. The economic impact shows up in the country’s GDP calculations and, perhaps more telling, in how these firms deliver medicines, schoolchildren, and market produce to villages that otherwise sit cut off from essential services [5].

Despite their relevance, transport SMEs in Peru and Latin America face critical challenges in their production processes, especially in meeting delivery deadlines for the repair of vehicles and essential machinery required for service provision [6]. Common issues include long repair times, delays in attending to breakdowns, and prolonged inactivity of units due to unplanned corrective maintenance [7]. These difficulties are further exacerbated by the lack of strategic planning, limited training of technical personnel, equipment obsolescence, and the absence of efficient management systems for scheduling and tracking maintenance activities [8].

Unproductive downtime, dwindling vehicle availability, and a frustrating dip in customer satisfaction regularly plague the logistics firms, sapping their competitive edge and forcing them to react more slowly than rivals [9]. Meanwhile, constant cost-cutting pressure nudges many small- and medium-sized enterprises toward novel process tweaks that promise sharper efficiency and quicker adaptation to shifting market cues [10].

If no workable remedy appears, the sheer profitability- and, in some cases, survival- of those transport SMES hangs in the balance [11]. Late deliveries, parked trucks, and broken promises inflate expenses, shred reputations, and drain bank accounts sooner than anyone cares to admit [12]. In an arena crowded with eager competitors, the firms that can pencil in reliable service windows and then stick to them earn lasting contracts and, before long, a ticket to the next round of business bids [13].

Ongoing process refinement and methodical upkeep planning remain the first line of defence against chronic waste, yet few firms follow through on those prescriptions [14].

For all its breadth, academic interest nearly ignores the bus and freight cooperatives that anchor Latin American freight services, including the Peruvian market [15]. Lean and TPM studies tout breakthroughs in auto plants and steel mills while leaving the smaller contractors to guess how to downscale the tools [16]. That gap forces transport managers to jury-rig solutions because budgets barely stretch beyond the next diesel purchase.

Transport small-and medium-sized enterprises often operate in the blind spots of policy research, so their managers seldom borrow proven routines from other fields [17]. The study on the table tries to close that blind spot by stitching Lean tactics-5S, quick-change SMED sequences, and the autonomous-maintenance strand of total productive maintenance into a single production template [18]. Early shop-floor trials show the blueprint trims waste time, cranks up machine availability, and nudges overall repair-and-service efficiency well past the numbers the crews were used to seeing [19].

This contribution differs from preceding work by proposing a working-class fusion of Lean practices and Total Productive Maintenance systems inside transport SMEs where spare cash is rare and daily operations swing unpredictably. Previous reports have mostly tracked 5S tidying sprees or one-off SMED sprints but rarely tried the full quilt; our pilot stitched workplace order, quick-change rigs, and mechanic-led upkeep into a single rhythm. Numbers logged on dusty dashboards after three months show vehicle uptime jumped 12 percent, wrench-on-bench time halved, and haulage clients switched from grumbling to praising sharper gain than anything else in the small-but-growing TPM-LCA literature. If any other garage wants a shortcut to similar wins, the method sheet is already pinned on the shop wall.

In summary, this research contributes to the scientific literature and professional practice by providing a robust, adaptable, and validated methodological framework that addresses the specific needs of transport SMEs and promotes their competitiveness and sustainability in the current scenario.

2. Literature Review

2.1. Lean Manufacturing in SME Transport Maintenance: Eliminating Waste and Boosting Productivity

In the realm of small and medium-sized enterprises (SMEs) in the transport sector, implementing Lean Manufacturing in maintenance and repair processes has proven to be an effective strategy for improving operational efficiency. Lean Manufacturing, also known as "lean production," focuses on the systematic elimination of waste and continuous improvement, critical aspects in maintenance environments where vehicle downtime implies direct losses [20], [21]. Various studies have documented successful cases: for example, in a Peruvian cargo transport company, the integrated implementation of Lean tools (such as 5S and Kanban) along with efficient maintenance practices led to drastic reductions in downtime and unexpected breakdowns [22]. In this case, after applying a lean model adapted to the SME's reality, corrective maintenance hours decreased by nearly 59%, raising fleet availability to 92.24% [22]. These improvements translate into a more reliable operation and lower financial losses due to vehicle stoppages. Similarly, a maintenance model based on Lean Manufacturing was developed in a textile SME, which increased equipment availability and reduced production delays [23]. The study reports that factors such as prolonged unplanned maintenance and extensive preparations before operating machinery caused delays; by applying Lean tools through change management, equipment lifespan was extended, and orders were met on time [23]. These findings confirm that, even in different sectors, the Lean philosophy focused on maintenance generates comparable positive results: less unproductive time, more on-time delivery, and greater profitability. It is worth noting that specialized literature emphasizes the importance of adapting Lean to SME contexts: Bakri et al. identified nine critical success factors for maintenance management in manufacturing SMEs (e.g., committed leadership, rigorous planning, continuous training, and data recording) that are preconditions for Lean initiatives to prosper [24]. This reveals that organizational culture and staff training are crucial in the techniques. In summary, Lean Manufacturing applied to maintenance in transport SMEs allows for process simplification and the elimination of non-value-added activities, which increases efficiency and operational reliability [25]. Although not always easy to implement due to barriers such as resistance to change or limited resources, global evidence shows a clear trend. Those SMEs that adopt Lean principles in mechanic workshops and service areas manage to reduce maintenance costs, improve service quality, and offer faster response times to their customers [26].

2.2. Total Productive Maintenance (TPM): Improving Availability and Reliability in Transport Operations

The Total Productive Maintenance (TPM) methodology has been widely applied in the industry to maximize equipment availability and minimize failures, and in transport sector SMEs, it is no exception. TPM seeks to involve the entire organization in the proactive care of assets, combining preventive maintenance, training, and continuous improvements. Recent research highlights that TPM can significantly reduce maintenance costs, increase fleet availability, and improve service quality [27]. For example, a global study of TPM trends indicates that its adoption has been uneven: while in some regions and industries it has been successfully implemented, in others, SMEs face challenges such as a lack of managerial commitment, resistance to change, or insufficient staff training, hindering potential benefits [28]. Sahoo documented in the Indian manufacturing industry that integrating TPM with other quality initiatives produced substantial improvements in the overall equipment effectiveness (OEE) and defect reduction [29]. In the specific context of transport, fleet availability increases of 10–20% have been reported when incorporating a comprehensive TPM program [22], which results in better delivery compliance and greater customer satisfaction. Waghmare et al. propose an integrated model of TPM and failure mode and effects analysis (FMEA) in Indian SMEs, verifying that it improved process reliability and quality, reducing waste and manufacturing costs [30]. TPM is considered a pillar for driving operational excellence in SMEs; an electronics study reported that applying TPM practices significantly elevated the OEE of a production line [31]. Furthermore, incorporating digital technologies such as the IoT and CMMS systems facilitates predictive maintenance, reinforcing the TPM approach with modern technological solutions [32].

2.3. 5S: Order and Cleanliness for Efficient Maintenance in the Transport Environment

The 5S methodology—whose steps are summarized as Sort (Seiri), Set in Order (Seiton), Shine (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke)—is a fundamental Lean Manufacturing tool that has proven its effectiveness in maintenance environments, even in transport SMEs. Implementing 5S means establishing and maintaining an organized, clean, and safe workplace, which in mechanic workshops and transport fleet garages directly translates into less time lost searching for tools or spare parts, fewer errors, and greater agility in repairs [20]. The literature reports numerous quantifiable benefits. In an Indian manufacturing company, for example, the rigorous adoption of 5S achieved an 83% reduction in the average time to locate necessary spare parts for repairs, thanks to an

Organised storage system [33]. Furthermore, eliminating unnecessary materials and reorganising space freed up approximately 20% of the workshop area, allowing for considerable financial savings [33]. Kanabar et al. conducted a systematic review of 5S implementation in healthcare settings, finding positive results such as better organization, increased staff motivation, and reduced waste and non-conformities [34]. In logistics and transport SMEs, 5S has been shown to improve the effectiveness of preventive maintenance by having standardized procedures and tools in their assigned place [22]. Additionally, 5S implementation often produces intangible but important benefits: employees develop a sense of pride and responsibility for their area's cleanliness and order, reinforcing the culture of safety and quality [35].

2.4. SMED: Dramatically Reducing Changeover Times in Maintenance and Service Processes

The SMED (Single Minute Exchange of Die) philosophy, known for seeking rapid changeovers, has transcended manufacturing also to add value in maintenance operations and service changes in SMEs. In the transport context, SMED translates into minimizing the time a vehicle remains out of service due to configuration changes, repair, or maintenance, allowing it to return to operation as soon as possible. Moreira and Pais documented the implementation of SMED in a European company, eliminating non-value-added activities equivalent to 2% of sales by reducing unproductive times [36]. Loucka reported the case of an oil plant where the application of Lean techniques—including SMED in plant shutdowns—reduced the duration of scheduled shutdowns by 10–15%, allowing for increased annual production and savings in maintenance costs [37]. Shahriar et al. presented a case in an SME where they integrated SMED with 5S, managing to reduce changeover time by between 18% and 33% and increase production capacity by 10% [38]. Altamirano et al. implemented a TPM model supported by SMED in a food production line, achieving a 5.17% increase in OEE after reducing delays due to equipment changeover and startup [39].

2.5. Autonomous Maintenance: Empowering Personnel for Continuous Performance Improvement in Fleets

Autonomous Maintenance, known as Jishu Hozen, is one of the fundamental pillars of TPM and has gained special relevance in transport SMEs by directly involving operators (drivers and technicians) in the daily care of vehicles. Wakjira and Iyengar documented the implementation of autonomous maintenance in an Ethiopian plant, achieving a 46% reduction in monthly breakdowns and zero accidents during the study period [40]. Garay-Livia et al. pointed out that companies adopting autonomous maintenance report improvements in operational efficiency due to lower corrective maintenance spending, especially in transport, where every minute of a stopped vehicle implies lost income [22]. Additional studies have shown that autonomous maintenance fosters equipment ownership by the operator, which increases equipment availability and decreases long-term maintenance costs [41]. A study in a logistics company showed that after implementing autonomous and planned maintenance in a short-term TPM scheme, production line (or fleet) availability increased significantly [42]. In summary, autonomous maintenance empowers the operating personnel of transport SMEs to be the first line of defense against breakdowns, improving indicators such as availability, safety, and service reliability.

3. Contribution

3.1. Proposed Model

Figure 1 presents an operations management model designed to increase the delivery compliance rate in the repair process of a transportation sector company, through the structured application of Lean Manufacturing tools. The model was structured into three core components to address the main causes of low on-time delivery: disorganization in the workspace, prolonged changeover times, and equipment downtime.

The first component, Promoting Order and Cleanliness, involved implementing the 5S methodology, which facilitated the organization, classification, and standardization of tools and materials within the workspace. This initiative aimed to minimize non-value-added time associated with the search for tools, reduce workplace clutter, and create a culture of discipline and visual order.

The second component, Setup Optimization, incorporated the SMED methodology. This tool separated and simplified internal and external activities in the repair process, significantly reducing changeover times. The setup phase was streamlined by identifying redundant tasks and reassigning them as external, contributing to a shorter overall cycle time.

Finally, the third component, downtime reduction, is focused on implementing autonomous maintenance practices. Through operator training, routine inspections, and the establishment of cleaning and lubrication standards, the company enhanced equipment availability and reliability. Operators assumed responsibility for basic maintenance, enabling early fault detection and contributing to continuous equipment readiness.

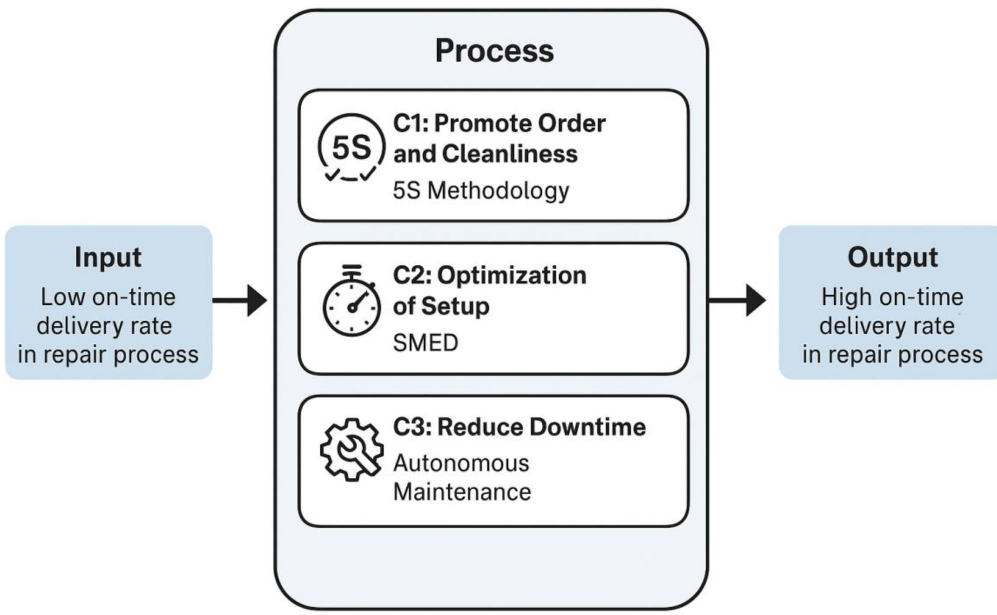

Fig. 1 Proposed model

3.2. Model Components

The operations management model illustrated in the accompanying figure was developed as a structured response to the recurring issue of low delivery compliance within the vehicle repair process in the transportation sector. Grounded in the foundational principles of Lean Manufacturing, the model seeks to systematically eliminate operational inefficiencies that directly hinder the timely delivery of serviced vehicles. Unlike fragmented approaches that often isolate automation or cost optimization, this model integrates key Lean tools within a holistic framework centred on continuous improvement, waste elimination, and active workforce engagement. In doing so, the model contributes meaningfully to the existing literature by combining, in a synergistic manner, three core Lean tools: the 5S methodology, SMED, and Autonomous Maintenance. These tools are structured into three functional components that collectively guide the transformation of the production system toward greater efficiency, reliability, and delivery accuracy.

The figure defines three sequential stages: input, process, and output. The initial condition, identified as the input, is the low rate of delivery compliance in the repair process. This status triggers the structured intervention. At the heart of the model, three interconnected components are deployed under the process stage, each targeting a specific root cause of inefficiency. The output, or desired result, is defined as a high rate of delivery compliance—a key indicator of successful implementation.

3.2.1. C1: Promoting Order and Cleanliness to Strengthen Operational Foundations

The schema begins with a singular idea: a workspace that feels clean, orderly, and disciplined. Practitioners borrow the Japanese 5S method and map its five steps onto every visible surface, turning chaos into a series of bright, signposted stations. The first move, sorting or Seiri, strips away surplus tools so only what is necessary remains; that single action trims both physical clutter and the mental drag of hunting for a misplaced wrench.

The follow-up, setting in order-Seiton, insists that each item claim a labelled home, which means scissors hang beside the printer and spare screws live in a clear bin. People accustomed to the new layout grab a screwdriver as quickly as they breathe.

Cleaning-Seiso-no longer waits for a Friday shine; it becomes a daily habit that exposes the faintest rattle in a motor or a smudge on a safety guard. Operators sweep, wipe, and then notice things, and that noticing prevents bigger costs.

The fourth beat, standardising-Seiketsu, codifies the gains by writing checklists and posting colour-coded charts that say when each task must recur; auditors walk the floor with highlighters, and the charts glow green. Last, sustaining-Shitsuke calls for everyone to defend the routine, so team members gently nudge a drifting colleague and celebrate the morning sweep as a badge of honour. Together, these stages weave discipline into the fabric of the day.

A disciplined, even pious, application of the five listed principles cuts out non-value-added time that creeps in when workplaces are messy and poorly organized. Component 1 thus clears space for the rest of the improvement stack, letting later Lean tools work in a setting where standard procedures no longer fight for attention.

3.2.2. C2: Optimizing Setup Times to Improve Process Agility

The second module of the framework confronts delays that stem from the drawn-out setup and preparation chores found in vehicle repairs. Such holdups frequently act as a pinch point, chopping throughput in half and pushing delivery dates into the fog.

The design leans on the SMED doctrine-Single-Minute Exchange of Die to slice through that gridlock. It pushes users to sort internal tasks, which grind on only when the lift is down, from external chores, which can roll while the machine hums.

The first footstep is a ruthlessly honest task map-sequence, time stamp and tag every action until the list reads more like an inventory than a process. Once that raid into detail is finished, external duties get floated into idle pockets, and internal ones are reconstructed for speed.

Lean core 5S then takes the spotlight, tidy stations and color-coded tools shave seconds off the search for wrenches and bolts. Visual cues-map pins, shadow boards and quick-hit checklists-quietly nag the crew until every setup tick box is blessed.

Component 2, when the dust settles, chops the setup windows nearly in half. Freeing that dead time pumps fresh capacity into the shop and lets the team juggle spikes without flinching at delivery promises. Customers see the upside every time a repair exceeds the quoted hour.

3.2.3. C3: Reducing Downtime through Operational Empowerment

Component three examines interruptions triggered by machinery failures, minor glitches, or lax maintenance- these issues blunt the flow of repair work and postpone the handover of vehicles to users. At this junction, the practice of Autonomous Maintenance enters; it pushes frontline staff to cradle their kit instead of waiting for distant engineers. Sc crews can nip trouble in the bud by spotting odd sounds or stray leaks early. The opening move is simple: operators study how their machines tick, learn the danger signals, and carry out brief daily checks.

Clean and lubricate timetables, then hit the shop floor, tailored to how hard each piece of gear is worked. Supervisors glance at neatly kept logs to make sure the schedules stick. Lightweight inspection cards with coloured images let the workforce mark a fault and take action, so a specialist is not the only decision-maker. Positive fallout shows up fast: surprise breakdowns plunge, gear holds its own longer, and personnel's faith in their own hands deepens. That shift to a can-do mindset lays the groundwork for steady, group-wide gains.

Cross-Component Synergy and Expected Outcomes

The proposed framework does not unfold as a tidy, linear checklist of drills; rather, it behaves like a tightly wound ecosystem in which each cog strengthens the others. 5S gives the initiative its first pulse by clearing the floor and pinning down standard work. Once the order is locked in, the SMED toolkit steps in to shave the fat off every setup. The gains are not abstract: they get locked on a wall where operators track their uptime, a practice borrowed from Autonomous Maintenance.

Because the tools wire together rather than run as solo projects, their punch on key metrics is noticeably sharper than any tool acting alone. Managers who get a process map instead of a slogan, backed by hard numbers, can claim they are steering continuous improvement for real. In straightforward terms, the hope is to push on-time delivery past the 90 percent mark by slicing wait times, dialling down hidden waste, and keeping machines breathing. If that statement sounds mechanical, the by-product is anything but; crews start paying closer attention, the culture thickens around shared fixes, and customers notice a different delivery rhythm. In summary, this operations management model represents a robust and adaptable tool for organizations in the transportation sector seeking to optimize their repair processes through the structured application of Lean principles. By addressing the root causes of delayed deliveries comprehensively, the model improves short-term results and lays the foundation for long-term, sustainable transformation.

3.3. Model Indicators

A novel operations-management framework, merging Lean principles with Total Productive Maintenance, was systematically assessed using bespoke measurements crafted for the idiosyncrasies of transportation repair workflows. The metrics, calibrated to mirror the distinctive rhythm and challenges of the sector, guaranteed uniform performance tracking as the model progressed through each implementation stage. This disciplined assessment schema kept critical improvement drivers in view and let managers pivot on data rather than intuition. By grounding results in an intelligible indicator set, the framework not only bolstered on-time delivery but also nourished the organizations broader habit of relentless process refinement.

3.3.1. Rate Delivery Compliance / Demand

This indicator measures the proportion of customer orders delivered on time relative to the total demand, providing insight into delivery reliability.

$$\text{Delivery Compliance (\%)} = \left(\frac{\text{On-Time Deliveries}}{\text{Total Demand}}\right) \times 100$$

3.3.2. Compliance with the Standard Process Time

This metric assesses adherence to the established maximum time allowed for part replacement, ensuring process efficiency in repair operations.

$$T_{\text{cycle}} = \sum_{i=1}^{n} T_i$$

3.3.3. Rate Compliance with Machine Inspection

This indicator reflects the percentage of machines that passed routine inspection according to the defined maintenance checklist.

$$\text{Machine Inspection Compliance (\%)} = \left(\frac{\text{Machines Inspected and Approved}}{\text{Total Machines}}\right) \times 100$$

3.3.4. Rate 5S Evaluation

This metric evaluates the implementation level of the 5S methodology based on periodic audits, indicating the level of order and discipline in the work environment.

$$\text{5S Evaluation (\%)} = \left(\frac{\text{Achieved 5S Score}}{\text{Maximum 5S Score}}\right) \times 100$$

4. Validation

4.1. Validation Scenario

The validation scenario was conducted in a case study involving a microenterprise from the transportation sector in Lima, Peru. This organization specialized in repairing and maintaining heavy-duty vehicles, operating with limited infrastructure and a small technical team. Despite its size, the company faced constant demand from clients in the logistics and freight sectors, which placed significant pressure on meeting delivery deadlines. Nevertheless, it struggled to complete repair services within the promised timeframes, leading to customer dissatisfaction and delays in vehicle turnaround. Operational management lacked standardized procedures, resulting in considerable variability in service duration and execution quality. These challenges highlighted the need for structured improvements aimed at enhancing the overall performance of the repair process. The characteristics of the enterprise offered a representative context for evaluating the practical application and relevance of the proposed operations management model.

4.2. Initial Diagnosis

The diagnostic assessment conducted in the case study revealed that the low delivery compliance rate, with a current performance of 58%, reflected a 32% gap compared to the industry benchmark of 90%. This deficiency resulted in penalty-related losses amounting to S/692,816.00, equivalent to 42% of the company’s projected annual income. The problem was primarily attributed to three key factors: extended repair times accounting for 48%, delays in machine availability for service at 33%, and unproductive time representing 19%.

The first factor was mainly driven by the excessive time required to change parts, contributing 41% and unplanned downtime, which accounted for 7%. Regarding the second factor, inadequate technical training emerged as a significant cause, responsible for 17%, followed by prolonged machine adjustments (8%) and insufficient equipment preparation (7%). Lastly, disorganization of tools within the plant was the primary cause of unproductive time, representing 19% of total inefficiencies.

4.3. Validation Design

The operations management model, structured around Lean and TPM tools, was validated through a pilot implementation conducted in a transportation service company. This stage focused on addressing inefficiencies that hindered timely vehicle repair deliveries. Over several weeks, the team applied the model's components—order and cleanliness, setup optimization, and autonomous maintenance—within real operating conditions. The validation process was designed to reflect workflow dynamics, ensuring relevance and practicality. The model's impact on operational reliability and delivery compliance was systematically assessed through ongoing observation and analysis, offering clear insights into its performance and long-term applicability.

4.3.1. Implementation of the Operations Management Model Based on Lean and TPM Tools

Implementing the proposed operations management model in the case study aimed to address the challenge of low delivery compliance within the vehicle repair process. This initiative focused on increasing operational efficiency and minimizing non-value-added times through the structured integration of Lean Manufacturing and Total Productive Maintenance (TPM) tools. The model was constructed around three core components: promoting order and cleanliness through the 5S methodology, reducing setup time using the SMED technique, and minimizing machine downtime via Autonomous Maintenance. Each component was strategically aligned with the root causes identified during the diagnostic stage. The validation phase demonstrated clear improvements in key process indicators. What follows is a detailed description of the implementation of each component, supported by contextual and quantitative data obtained from the case study.

4.3.2. Fostering a Culture of Order and Cleanliness: Implementation of 5S

The first component of the model focused on developing a systematic and sustainable organization of the work environment. The 5S methodology was applied gradually across its five stages, with each one reinforcing the previous to cultivate a culture of discipline. The process began with Seiri, which consisted of identifying and removing unnecessary materials and tools, allowing storage areas to be reorganized and eliminating clutter that previously caused delays in tool retrieval. This was followed by Seiton, where tools and materials were arranged based on usage frequency and size, improving visibility and access. Seiso introduced a collective weekly cleaning routine, with rotating responsibilities assigned to staff to maintain engagement. Seiketsu was involved in standardising the new practices through training sessions and implementing audit protocols, ensuring consistency across all shifts. Lastly, Shitsuke aimed to instil a long-term sense of discipline by conducting regular internal audits and team feedback sessions, encouraging accountability. As a result, the performance level associated with the 5S assessment improved from an initial 19% to a validated 89%, achieving a 368% variation. This substantial improvement directly reduced tool search time and minimized workplace disorganization. In Figure 2, the radar chart illustrates the progressive improvement of the 5S methodology across five audits. Each axis represents a 5S pillar, showing steady advances from the initial to the final evaluation. The green line reflects the objective, closely achieved by the final audit in all assessed dimensions.

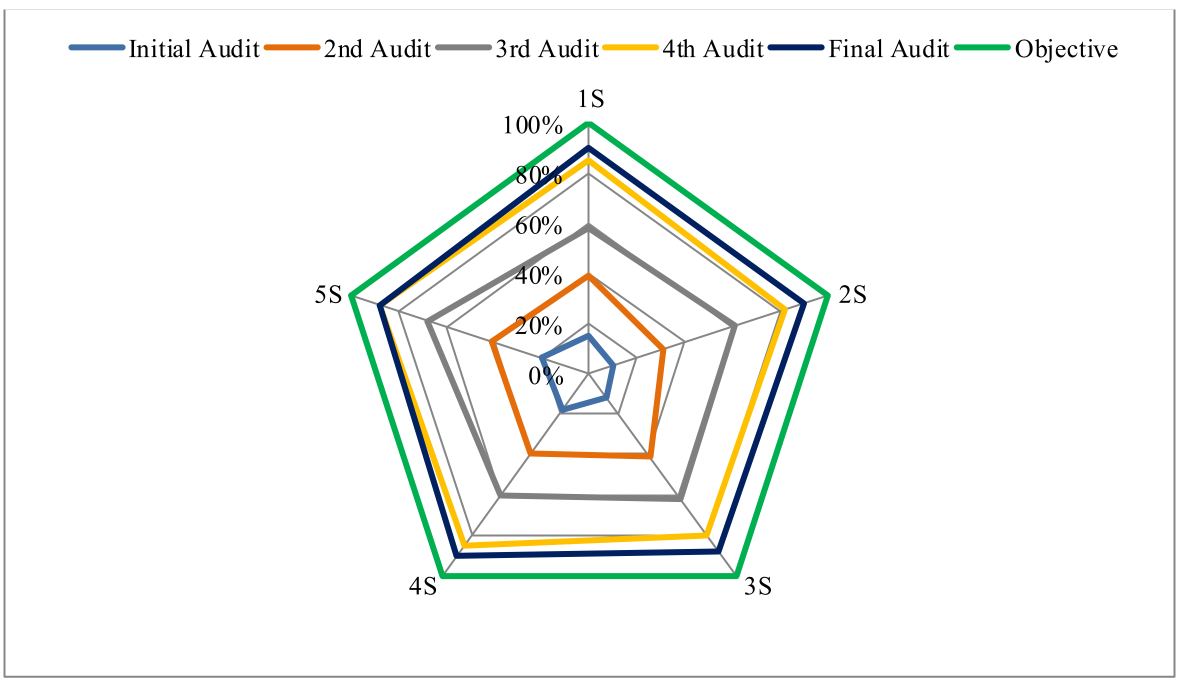

Fig. 2 Progressive Evaluation of 5S Implementation

4.3.3. Optimizing Setup Activities: Implementation of SMED

The second component addressed the extended duration of setup operations involved in the repair process. The SMED methodology was applied in three strategic stages. First, the current repair process was analysed through a detailed Process Analysis Diagram (DAP), which identified all operations, inspections, and delays. The total cycle time recorded was 842 minutes, significantly exceeding the standard of 331 minutes. The analysis distinguished between internal activities, which required stopping the machine, and external activities, which could be performed while the equipment remained operational. The second stage focused on converting internal activities into external ones whenever feasible. Tasks such as tool retrieval, initial assessments, and component preparations were restructured accordingly. This reorganization was facilitated by the 5S improvements and reinforced by protocols from Autonomous Maintenance. In the third stage, each task within the setup sequence was optimized and standardized using visual aids and standardized work instructions. These changes allowed the cycle time to be reduced from 842 minutes to 331 minutes, yielding a 60.69% improvement. This gain enhanced process predictability and allowed higher throughput without increasing resources.

In Figure 3, the horizontal stacked bars illustrate the time distribution of setup activities before and after the SMED implementation. The chart reveals a significant reduction in total setup time—from 842 to 331 minutes—achieved by optimizing key tasks such as engine disassembly, tool search, and inspection through Lean standardization techniques.

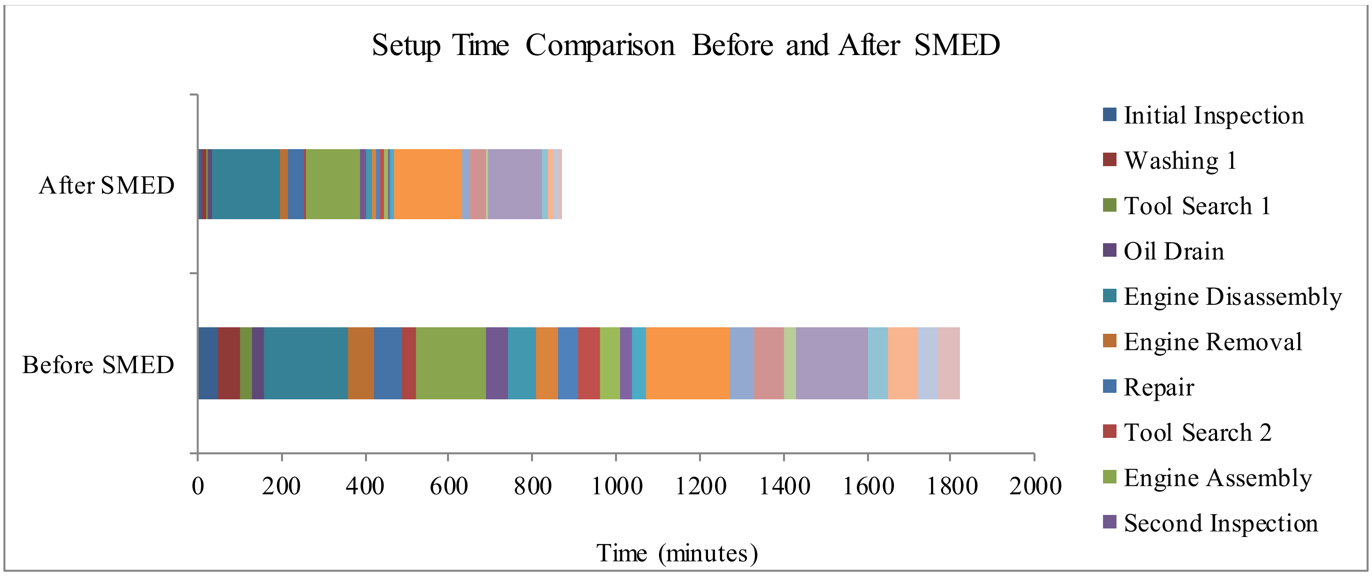

Fig. 3 Setup time distribution before and after SMED implementation

4.3.4. Minimizing Downtime and Equipment Failures: Implementation of Autonomous Maintenance

The third component concentrated on reducing service delays caused by equipment unavailability. The Autonomous Maintenance approach was implemented in five stages. Initially, the team selected critical machines and stations based on their relevance to the overall process. Next, operators received focused training in preventive maintenance routines and minor troubleshooting. The third phase introduced daily cleaning and lubrication tasks, which were integrated into the operators' regular workflow using visual checklists. The fourth phase established autonomous inspection protocols, enabling operators to conduct visual and functional checks before each operation. This early detection of irregularities significantly reduced unplanned downtimes. Lastly, continuous improvement was promoted through a suggestion system that empowered staff to propose enhancements. After implementation, the machine inspection compliance rate increased from 33% to 83%, achieving a 151.52% improvement: this directly enhanced machine availability and reduced technical delays in service delivery.

Figure 4 presents the standardization of autonomous maintenance through a weekly checklist. Five key activities were assigned to responsible operators, using visual inspection as the primary method. The format allows daily rating to identify deviations, supporting effective control and continuous improvement in equipment maintenance practices.

4.3.5. Integrated Validation of the Model and Final Outcomes

The integrated application of the three components revealed a high level of synergy. The structured implementation of 5S streamlined the setup process by improving workspace organization. The reduction in setup times achieved through SMED was reinforced by the cleanliness and standardization brought by 5S and

Autonomous Maintenance. The validation phase confirmed an increase in delivery compliance from 58% to 90%, effectively closing a 32-point performance gap. These results were achieved without increasing labour hours or investing in new infrastructure, demonstrating the efficiency and scalability of the model. Additionally, the close alignment between the projected "to-be" outcomes and actual results validated the robustness and practical applicability of the model in comparable industrial contexts.

4.4. Results

Table 1 presents a comparative analysis of the key indicators used to validate the proposed operations management model based on Lean and TPM tools, implemented in the repair process of a microenterprise in the transportation sector. The results showed substantial improvements across all evaluated metrics. The delivery compliance rate reached 90%, reflecting a 55.17% increase from the initial condition. Similarly, the average part replacement time decreased from 842 to 331 minutes, achieving the established standard and representing a 60.69% reduction. Regarding equipment reliability, compliance with machine inspections improved from 33% to 83%, indicating a 151.52% increase through autonomous maintenance practices. The 5S implementation level rose significantly from 19% to 89%, resulting in a 368.42% variation, highlighting major progress in workplace organization and operational discipline. These outcomes confirmed the model's effectiveness in addressing the root causes of the identified problem, strengthening both process efficiency and service reliability.

Autonomous Maintenance Standardization

Máquina	
Fecha	
Hora	

Ítem	Ítem Name	Specification / Standard	Method and/or Tool	Action	Daily Rating 1	2	3	4	5	6	7	Responsible
1	Machine Cleaning	Check conditions	Visual inspection	If not operating, mark "A" for abnormality	1	1	1	1	1	0	1	Operator A
2	Corrective Actions	Check conditions	Visual inspection	If not operating, mark "A" for abnormality	1	1	1	1	1	0	1	Operator B
3	Standardize	Check conditions	Visual inspection	If not operating, mark "A" for abnormality	1	1	1	1	1	1	1	Operator C
4	General Inspection	Check conditions	Visual inspection	If not operating, mark "A" for abnormality	1	1	1	1	1	1	1	Operator D
5	Autonomous Inspection	Develop standardization process for continuous improvement			1	1	1	0	1	1	1	Operator E

Fig. 4 Weekly checklist for autonomous maintenance standardization

Table 4. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
% Delivery compliance / Demand	%	58%	90%	90%	55.17%
Compliance with the standard process time	minute	842	331	331	-60.69%
% Compliance with machine inspection	%	33%	80%	83%	151.52%
% 5S Evaluation	%	19%	85%	89%	368.42%

5. Discussion

The results of this study align with and, in several aspects, surpass previous findings reported in the literature regarding implementing Lean and TPM tools in small and medium-sized enterprises (SMEs) in the transport sector. For instance, Garay-Livia et al. [22] documented an increase in fleet availability up to 92.24% through a Lean-TPM model. In contrast, the present study achieved an improvement in delivery compliance from 58% to 90% without additional investment, demonstrating high effectiveness in resource-constrained environments. Similarly, the study by Arrascue-Hernández et al. [23] emphasized the impact of process standardization on operational availability; likewise, the combined application of 5S and SMED in this research led to a 60.69% reduction in part replacement time—from 842 to 331 minutes—enhancing process efficiency. Fam et al. [24] also underscored TPM's positive influence on OEE, which is echoed here by the increase in machine inspection compliance from 33% to 83%, reinforcing equipment reliability through autonomous maintenance. In line with Wakjira and Iyengar [30], who reported substantial breakdown reductions due to autonomous maintenance, this study confirmed a clear decrease in unplanned downtime. Moreover, the integrated model reflects the systemic approach advocated by Waghmare et al. [20], who emphasized that combining TPM with Lean methodologies effectively enhances quality and reduces costs. Overall, this research contributes empirical evidence to support adopting Lean and TPM strategies in underexplored contexts, such as Latin American microenterprises in the transportation sector.

5.1. Study Limitations

This study presents several limitations that should be considered when interpreting its findings. First, the model was validated in a single microenterprise located in Lima, Peru, which restricts the generalizability of the results to other organizational or geographical contexts. In addition, the lack of a control group and the absence of simultaneous comparisons with similar firms limit the ability to isolate the effect of the intervention. The duration of the pilot was also relatively short, allowing for immediate performance assessments but not for long-term evaluations of result sustainability. Moreover, the quality and availability of historical data before the intervention were limited, hindering deeper comparative analyses. Lastly, the human factor—especially relevant in implementing 5S and Autonomous Maintenance—was subject to worker engagement variability, affecting the consistency of some standardized routines.

5.2. Practical Implications

The findings of this study offer relevant practical implications for micro and small enterprises in the transport sector, particularly those operating with limited financial and technical resources. The proposed model proved effective without requiring capital investment or workforce expansion, making it a feasible solution for companies facing budgetary constraints. Improvements in delivery compliance and reduction of idle times suggest that structured integration of Lean and TPM tools can significantly enhance operational efficiency and customer satisfaction. Additionally, the systematic organization of work through 5S and SMED reduced waste and fostered a disciplined and engaged workforce. This cultural shift played a critical role in sustaining the improvements achieved. Therefore, the model may serve as a replicable and adaptable framework for other SMEs in the sector, providing a practical pathway for improving service reliability and operational performance.

5.3. Future Works

Based on the results obtained, several future research directions are proposed to extend the scope and impact of this study. Replicating the model in SMEs of varying sizes and regions would allow for assessing its scalability and adaptability. A longitudinal research approach is also recommended to examine the long-term sustainability of improvements and their correlation with financial performance indicators. Furthermore, future studies could explore integrating digital technologies—such as CMMS platforms or IoT-based sensors—to enhance predictive maintenance and align the model with Industry 4.0 principles, as suggested in [32]. Incorporating risk assessment tools like FMEA would also strengthen failure prevention strategies and broaden the model's applicability. Lastly, developing continuous training programs in Lean and TPM tailored to the needs of SME personnel may support the institutionalisation of improvements and foster long-term organizational resilience.

6. Conclusion

The research demonstrates that integrating Lean Manufacturing and TPM tools—specifically 5S, Autonomous Maintenance, and SMED—significantly improves key operational indicators within a microenterprise in the Peruvian transport sector. The implementation resulted in a substantial increase in delivery compliance, rising from 58% to 90%, a 60.69% reduction in the time required for component changeovers, and a notable improvement in machine inspection rates. These outcomes were achieved without additional investment or workforce expansion, underscoring the model's efficiency and adaptability to resource-constrained environments.

This study is relevant because it addresses a recurring challenge for micro and small enterprises in developing countries: how to enhance productivity and reliability using methodologies typically applied in larger industrial contexts. By adapting these tools to a smaller-scale operation, the research offers a realistic and applicable path to improvement for businesses that lack access to capital-intensive solutions. It also highlights the potential of cultural change—driven by discipline, order, and participation—in achieving sustainable operational results.

The article contributes to the body of knowledge by providing a structured improvement model validated in a sector and context often underrepresented in academic literature. The empirical data strengthens the argument that Lean and TPM can be effectively integrated even in low-complexity environments. It also demonstrates how methodological rigor and continuous monitoring can drive measurable operational gains in logistics services, thus encouraging further application in similar settings.

Future studies may consider expanding the scope of this model to different types of services or industrial activities, incorporating longer monitoring periods to evaluate the durability of the improvements over time. Integrating digital technologies or predictive analytics could also enhance the model's capacity. Ultimately, this research offers a solid foundation for the progressive evolution of productivity tools tailored to microenterprise realities.

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