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Original Article

Lean-TPM Model for Operational Reliability in Logistics: A Case Study in the Cleaning and Hygiene Distribution Sector

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Abstract: *Mass-consumption distribution companies in Latin America face growing pressure to improve efficiency while ensuring service reliability. Although Lean and TPM methodologies have proven effective in manufacturing environments, few studies explore their integration in logistics operations. This research addressed operational inefficiencies in a medium-sized Peruvian company by proposing a Lean-TPM model tailored to reduce delays, minimize failures, and enhance delivery performance. The model incorporated standardized procedures, autonomous maintenance, and error-proofing mechanisms supported by engineering controls. After implementation, the OTIF indicator improved from 91.9% to 97.05%, MTBF rose to 361 hours, and MTTR was halved. Safety incidents were eliminated, and pallet and truck assembly times were significantly reduced. These outcomes confirm the model's viability and suggest its relevance beyond the studied case. By bridging theory and practice, the study contributes to industrial engineering literature and supports sustainable logistics in emerging economies. Future research is encouraged to replicate the model and explore its integration with digital tools and environmental goals.*

Keywords: *Lean Manufacturing, Total Productive Maintenance, Logistics Efficiency, Autonomous Maintenance, Poka-Yoke, OTIF Performance.*

I. INTRODUCTION

This research focuses on mass consumer distribution as it profoundly impacts the world economy by providing consumers with critical goods and services. The mass consumption industry not only generates an increasing share of the world GDP, but it is also vital for employment opportunities, and economic prosperity, particularly for countries like Latin America and Peru [1][2]. In Peru, this industry has greatly expanded over the past ten years due to heightened urbanization alongside the increased purchasing power of consumers [3]. Such circumstances have compounded the problems for firms operating in this industry and compelled them to adjust almost instantaneously to a rapidly shifting and highly competitive landscape.

Despite this, companies distributing mass consumer products face significant challenges in their production and distribution processes that directly impact their performance. One of the most critical issues is the low OTIF (On Time In Full) compliance rate, which often falls below industry standards due to operational inefficiencies. These inefficiencies are evident in the loading of trucks at distribution centres as well as in the poor maintenance of pallet preparation equipment, resulting in operational failures [4][5]. Studies have documented that these inefficiencies not only affect customer satisfaction but also lead to avoidable economic losses [6].

To address these controllable issues, it is critical companies find methodologies designed to optimize their processes. Tools such as Lean Manufacturing and TPM (Total Productive Maintenance) have emerged as effective approaches to operational efficiency, waste reduction, and product quality improvements [7][8]. The implementation of lean practices related to work standardization and Poka-Yoke error prevention have proven effective on the identified pallet loading and equipment maintenance inefficiencies [9][10]. This could not only improve the OTIF rate, but in a broader scope contribute to the sustainable development of operations on the vertical in the long term.

Regardless of the increasing use of such methodologies, there remains a gap within the literature that needs to be addressed. Most prior research concentrates fully upon the application of Lean on manufacturing industries without paying adequate attention to cases for distribution companies in Latin America [11][12]. The goal of this study is to broaden the context of Lean approaches to develop a production model for mass-consumption distributors that integrates Lean and TPM tools.[13][14]

The distribution industry has been largely neglected in academic research and a sustained focus on its challenges is what makes this study distinct. When conducting this research and drawing from the literature focused on Lean in traditional industries, it becomes clear that while numerous studies demonstrate significant improvements in defect rates and operational efficiency, there is a conspicuous absence of work centered on the mass consumption distribution sector

[15][16]. This gap is an opportunity to greatly enhance and transform operations in this region, striving for better efficiency, sustainability, and responsiveness to market demands.

Thus, this research aims to comprehensively analyze the issues encountered by companies engaged in mass distribution of consumers' goods and develop a theoretical and practical model for the application of adapted Lean and TPM methodologies to aid these companies in operational efficiency improvement and responsiveness to the shifts in consumer demand within a competitive and fast paced business environment.

II. LITERATURE REVIEW

A. Lean Manufacturing: Optimization in Mass Consumption Logistics

Practitioners of lean manufacturing have been the focus of many scholars in logistics and mass consumer enterprises. This methodology enhances customer value by reducing wastes or in other words increases value that can be obtained from a resource, which, in this case, is important in an area that warrants effectiveness and reduction of costs. For example, Džubáková and Kopták's study underscores that process standardization through lean techniques foster improvement in service quality and greater market responsiveness amid stiff competition [17]. Here, Zumarán's study on the use of standardized work and CVRPTW (Capacitated Vehicle Routing Problem with Time Windows) illustrates how these tools increase OTIF (On Time In Full) in fruit logistics showing the application of the Lean approach to bolster performance indicators in the supply chain [18]. Further to this, Bragança and Costa's work builds on the assertion that the approach not only enhances the development of leaner systems, but that it also fosters a culture of continuous improvement in organizations [19].

B. Standardization of Work: Continuous Improvement in Logistics

The Standardization of Work practices has proven to be effective in improving the logistics processes of mass consumption firms. As Corbitt and Bronger explain, "Standardization not only creates clear procedures, but provides structure to operational measurement, training, and performance evaluation, thereby contributing to efficiency." [20] Kopták et al. explored the case of standardization and established that third-party logistics operations greatly improved with the use of standardization methodologies through a considerable reduction in error rates and improved service quality [21]. Also, Menard's analysis emphasizes on the fact that standardization of logistics processes provides structures that are necessary for the continuous improvement of the operational activities [22]. In the same manner, Zumarán's most recent research emphasizes the significant contribution of the standardization of work towards the improvement of the OTIF index and underscores the essence of these methodologies for competitiveness [18].

C. Poka-Yoke: Preventing Errors in Logistics Systems

The Poka-Yoke approach, which focuses on errors and defects prevention in production, originated in Japan. Its adaptation to logistical systems in mass consumption companies has proven effective in reducing costly issues stemming from errors. Ghadge and Mone explain how Poka-Yoke systems can be integrated into the assembly line to create a quality assured delivery by eliminating error detection at the realization stage [23]. Moreover, Vidor and Saurin's analysis claims that applying Poka-Yoke systems in inspection and maintenance is likely to improve operational efficiency significantly while maintaining a high quality of service [24]. Furthermore, Prabowo and Aisyah's research claims that adopting Poka-Yoke in various sectors increases operational efficiency as defects decline and machinery usage improves [25].

D. Total Productive Maintenance: Enhancing Logistics Efficiency

Total Productive Maintenance (TPM) is a management strategy focused on enhancing productivity through active maintenance of equipment and participation by staff at all levels in processes. In the scope of logistics pertaining to mass consumer products, it has been shown that TPM is essential in ensuring uninterrupted and dependable operations. Research on the implementation of TPM in logistics reveals that adopting preventive and predictive maintenance techniques remarkably mitigates downtime attributed to equipment breakdowns, which enhances customer satisfaction [26]. Moreover, Mazzinghy et al. assert that the implementation of maintenance management systems under ISO/IEC standards in the logistics branch not only improves operational efficiency but also bolsters customer satisfaction [27]. Equally, Bilous et al.'s work suggests that TPM practices are instrumental for differentiating factors in logistics of pharmaceutical firms where the reliability and speed of servicing their clients is crucial for maintaining market competitiveness [28]. Lastly, companies adopting TPM reap the benefits of incurring lower operational costs while lifting the standard of service quality offered to their clients [26].

E. Autonomous Maintenance: Empowerment of Logistics Personnel

The concept of Autonomous Maintenance (AM) advocates for the active participation of employees in the maintenance of their assets through training. This approach is particularly important in logistics settings where speed and efficiency are critical. The implementation of AM allows for self-operators where the operators of the machines become the primary maintainers. This improves reliability. From the information gathered, it appears that companies with MA practices tend to have lower maintenance costs, increased staff morale, and higher productivity. An improvement in morale suggests that ATT leads to greater commitment [29]. A logistic sector study underlines that Autonomous Maintenance fosters an ownership culture that drives continuous improvement [30]. Lastly, Kyung & Zhang's analysis points out that ATT can enhance performance in logistic firms and promote the adoption of additional quality and efficiency systems [31].

III. CONTRIBUTION

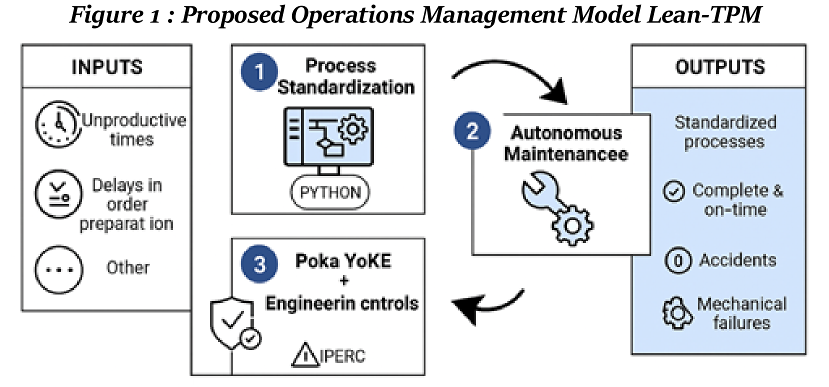
The materials and techniques section should include enough information to allow all operations to be replicated. If numerous procedures are presented, it may be separated into heading subsections. (Size 10 & Regular)

A. Proposed Model

The proposed operations management model was designed for a medium-sized company specializing in the commercialization of cleaning and hygiene products, integrating the principles of Lean Manufacturing and Total Productive Maintenance (TPM) with the objective of optimizing operational efficiency. As shown in **Figure 1**, the proposal was structured based on the identification of unproductive times and delays in order preparation, factors that negatively affected the logistics chain. In response, the first phase focused on process standardization, supported by the development of programming tools to ensure operational consistency. Subsequently, autonomous maintenance was incorporated as a strategy to promote proactive equipment care, minimizing unplanned corrective interventions. Finally, error prevention

Mechanisms were implemented through Poka Yoke devices and engineering controls, complemented by a risk analysis using hazard assessment methodologies. This methodological integration allowed the design of a flexible and replicable model aimed at strengthening process reliability, eliminating waste, and consolidating an organizational culture focused on continuous improvement, adapted to the specific characteristics of the cleaning and hygiene products sector.

Figure 1 : Proposed Operations Management Model Lean-TPM



B. Model Components

In the context of business competition and the demand for operational effectiveness, the contemporary model of operations management can be viewed as a strategic framework aimed at servicing medium-sized businesses involved in the distribution of cleaning and hygiene products. It was developed using the basic concepts of Lean Manufacturing and Total Productive Maintenance (TPM). These philosophies when put together synergistically allow organizations to optimize their processes, reduce waste, and improve equipment reliability. The model solves some of the major gaps related to inefficiencies in relation to logistics and operations in a holistic manner, as shown in Figure 1. The model adopts a structured and systematic approach to capture the available value through operational clean management, which, to our knowledge, has not yet been widely documented in the operational management literature. By process definition, active self-performance Standard Operating Procedures (SOPs), maintenance, and prevention of basic failures ensure that the proposed plan will positively influence the operational results and creates a focused vision of enduring achievement.

a) Stage 1: Improving Efficiency Through Process Standardization

The first pillar of the model describes standardization as a unified process, which serves as the operational groundwork on which later enhancements are positioned on. This stage realizes that the inconsistency in procedures leads to variability, mistakes, and inefficiencies, which impact service reliability. To solve this problem, the model suggests a comprehensive mapping of key operational activities with particular focus on the definitions of workflows, resource distributions, and timing allocations. The application of programming customization, such as Python-based scripts, enhances this goal by automating deviation detection, monitoring compliance in real time, and ensuring set standards are met. As a result of this intervention, the company can lower operational variability and sustain an organizational culture where so-called "bounded concreteness" flourishes; a situation where what is required to be done and what needs to be executed are unambiguously defined. The standardization process, instead of assuming the role of a static system or inflexible mechanism, is conceptualized as a dynamic structure open to change and continual improvements.

b) Stage 2 : Encouraging Equipment Maintenance via Autonomous Management

After setting the procedures' standardization, the model is ready to progress to the second stage of autonomous maintenance implementation. This block aims at forming the operational autonomy of the staff by providing them with the necessary resources and authority to conduct simplistic equipment maintenance on their machines. The rationale underlying this approach is quite simple but very powerful: the people who work with the equipment daily are the most capable of preventing equipment deterioration by early detection of anomalies. The model suggests that operators be trained in basic maintenance techniques such as lubrication, tightening, and visual checks that are accompanied by dynamically created checklists specific to every equipment type. Such active participation helps to not only minimize unplanned correctional measures but also fosters a greater sense of ownership and responsibility for equipment among the employees. In addition, the model also suggests the development of equipment condition reporting skills such as wall images and autonomous maintenance dashboards that promote maintenance attendance and encourage openness towards equipment conditions across the organization.

c) Stage 3: Poka Yoke and Engineering Controls Error Prevention

This stage of the model focuses on the elimination of operational errors using Poka Yoke devices in conjunction with engineering controls. Considering that human error, in most cases, is a major contributor to quality and safety incidents, the model stresses designing processes and equipment that, at the least, could prevent errors or make them obvious at a glance. In this sense, auxiliaries like limiters, elbows, guiding cylinders, and color indicators incorporated into the workstations are proposed to be simple, yet effective. At the same time, the model incorporates advanced engineering solutions such as fail safes and other automation that serve as added-defensive layers to deviations. Integrated for a holistic approach to risk management, the model adopts the IPERC methodology (Identification of Hazards, Assessment of Risks, and Control of Risks) as a systematic approach to the identification of critical points prone to errors that require prompt action with predefined measures and defining the necessary preventative mechanisms. This model stage promotes a safer and more predictable work environment while minimizing failures, therefore achieving operational excellence objectives.

d) Incorporating Stages: Continuous Improvement Cycle

Even if each stage of the model is built stepwise, its optimal value can be harvested when perceived as a cycle of improvement saga. The achievement of Poka Yoke and engineering controls is sustained by elaborate standardization policies, which facilitate the self-maintenance. The tight coupling of these factors strengthens the performative loop of operations and drives proactive maintenance while error-proofing enhances the provability of the standardized work instructions. The model suggests adding an appraisal and feedback session to every iteration of the cycle to improve the incorporation of the lessons learned and systematically fine-tune the processes. This way, the organization not only internalizes the changes but also builds a culture that thrives on flexibility, sustainability, and creativity.

e) Strategic Alignment with the Criteria of the Cleaning and Hygiene Industry

An essential aspect of the model is its alignment with the operational challenges faced by companies distributing cleaning and hygiene products. In this sector, characterized by the need to manage diverse inventories, respond promptly to customer demands, and ensure strict compliance with health and safety regulations, the proposed model offers tangible advantages. The emphasis on process standardization reduces errors in order preparation, ensuring complete and accurate deliveries. The autonomous maintenance strategy minimizes equipment downtimes, which is crucial for maintaining the agility of distribution operations. Additionally, the incorporation of error-proofing mechanisms enhances compliance with quality and safety standards, strengthening customer trust and market reputation. By addressing these sector-specific requirements, the model proves to be not only theoretically sound but also practically relevant and adaptable to the operational reality of the target companies.

f) Organizational Impact and Development of Operational Capabilities

The application of the Lean-TPM model has great effect in fostering the growth of organizational internal capabilities. In addition to the achievement of improvements in certain process indicator metrics, the model brings about the development of multidisciplinary teams that have the capability to analyze processes, diagnose problems, and implement workable solutions that can be sustained over time. Employees transform from being passive participants who only follow instructions to proactive members who actively engage in the management and ongoing refinement of business operations. This change results in enhanced organizational commitment, motivation, sense of belonging, and other critical factors that further strengthen organizational cohesion and resilience. From the standpoint of management, the model offers a more refined approach to decision-making by providing objective information and systematic risk evaluation which improves operational strategic management and supports the realization of sustainable business aspirations.

The proposed operations management model represents a solid and sustainable proposal for medium-sized companies seeking to enhance their competitiveness in the cleaning and hygiene products distribution sector. By integrating the principles of Lean Manufacturing and Total Productive Maintenance in a coherent and practical manner, and by addressing operational inefficiencies from a systemic and preventive perspective, the model transcends isolated improvements and promotes a deep organizational transformation. The deliberate construction of a dynamic and iterative cycle of standardization, maintenance, and error prevention enables companies not only to respond effectively to current operational challenges but also to develop the capabilities necessary to adapt and thrive in an increasingly demanding and changing market environment. The methodological rigor, practical relevance, and adaptability demonstrated by the model contribute substantively to the enrichment of the scientific literature on operational management, offering a reference framework that can be expanded and validated through future research and applications in diverse industrial contexts.

C. Model Indicators

The operational performance of medium-sized enterprises dedicated to the distribution of cleaning and hygiene products was evaluated through a management model based on the principles of Lean Manufacturing and Total Productive Maintenance (TPM). Designed with the primary objective of increasing the On-Time In-Full (OTIF) rate, specific measurement criteria were adapted to the needs of the sector, enabling a structured and comprehensive analysis. This methodological approach ensured detailed monitoring of operational variables and reinforced continuous improvement initiatives within the supply chain, enhancing service performance and operational reliability.

a) OTIF (On-Time In-Full)

This indicator measures the percentage of customer shipments delivered complete and on time. It reflects service reliability and customer satisfaction levels in the distribution process.

$$\text{OTIF} = \left(\frac{\text{On-time shipments}}{\text{Total shipments}}\right) \times 100\ \% \tag{1}$$

b) MTBF (Mean Time Between Failures)

MTBF represents the average operating time between equipment failures. It provides a clear insight into system reliability and maintenance performance over a given period.

$$\text{MTBF} = \frac{\text{Total operating time}}{\text{Number of failures}} \tag{2}$$

c) MTTR (Mean Time to Repair)

MTTR calculates the average time required to repair equipment after a failure. Lower MTTR values indicate quicker recovery and better maintenance practices.

$$\text{MTTR} = \frac{\text{Total repair time}}{\text{Number of failures}} \tag{3}$$

d) Safety Incidents

This indicator tracks the number of recordable safety incidents within the operational environment. It helps monitor the effectiveness of health and safety protocols in place.

$$\text{Safety Incidents} = \text{Number of recordable safety incidents} \tag{4}$$

e) Product Pallet Assembly Time

It measures the average time taken to assemble products onto pallets, based on the number of double-deck truck shipments. It highlights operational efficiency during loading activities.

$$\text{Product Pallet Assembly Time} = \frac{\text{Product pallet assembly time}}{\text{Number of double-deck truck shipments}} \tag{5}$$

f) Double-Deck Truck Internal Structure Assembly Time

This indicator assesses the average time needed to assemble internal structures within double-deck trucks, supporting improvements in loading processes and operational planning.

$$\text{Internal Structure Assembly Time} = \frac{\text{Assembly time of double-deck truck internal structures}}{\text{Number of double-deck truck shipments}} \tag{6}$$

IV. VALIDATION

A. Validation Scenario

The validation scenario was carried out in a case study involving a medium-sized company engaged in the commercialization of cleaning and hygiene products, located in Lima, Peru. This organization operated within a dynamic sector, where timely and complete deliveries were critical to maintaining customer satisfaction and competitiveness. The case study faced operational challenges that affected the consistency and efficiency of its logistics chain, mainly reflected in service levels. The need to strengthen process reliability and minimize inefficiencies justified the development of a tailored operations management model adapted to its specific requirements.

B. Initial Diagnosis

The diagnostic assessment conducted in the case study revealed a low On-Time In-Full (OTIF) performance in product deliveries to modern channel customers, with a current rate of 91.9% compared to the reference standard of 95%, resulting in a technical gap of 3.1%. This deficiency generated an economic impact equivalent to 190,301 PEN, representing 5.20% of the invoicing for the modern channel. The main reasons identified were unproductive times during the loading of double-deck trucks, accounting for 42% of the incidents, and orders not being prepared on time, representing 38%. Root causes included errors in assembling the internal structure of double-deck trucks (65%), safety incidents (45%), mechanical failures of the semi-automatic wrapping machine (48%), and errors in assembling products on pallets (37%). Additionally, 20% of the detected problems corresponded to other minor causes.

C. Validation Design

The validation of the operations management model, integrating Lean Manufacturing and Total Productive Maintenance (TPM) tools, was conducted through a structured pilot study in a medium-sized company dedicated to the commercialization of cleaning and hygiene products. The validation process lasted four months and focused on improving service levels by applying standardized workflows, workplace organization, and autonomous maintenance practices. The structured action plan addressed operational inefficiencies that affected delivery performance, aiming to optimize resource utilization and reduce service delays. This data-driven validation approach enabled a systematic assessment of the model's impact on operational efficiency and its feasibility for sustainable application in the sector.

Within the outline of the operational strategy aimed at enhancing the OTIF performance metric in a medium-sized firm dealing with distribution of cleaning and hygiene products, a particular model was developed and solved using Lean Manufacturing tools. This intervention was structured into the complementary phases of process standardization, autonomous maintenance, and the combined application of Poka Yoke and engineering controls. Each of these components was tailored toward the solution of root causes such as the pallet build-up, recurring mechanical failures, and the safety concerns related to the assembly of internal double-deck truck structures. The technical design was systematized based on quantitative figures, purpose-built systems, and exhaustive work instruction documents. Each key cause was strategically tied to an actionable critical improvement tool tailored for optimal mitigation of non-productive time, error prevention, and safe logistics, emphasizing the structural, procedural, and safety aspects underpinning human-machine interaction. Accompanying the implementation phase, these changes were incorporated into training materials, along with monitoring the operations, and an adaptable, long-term improvement cycle that sustains the center's operational efficiency.

a) *Process Standardization: Optimizing Pallet Assembly*

Eliminating errors at the subjective operator's decision-making level, as well as minimizing the time spent on the task, is what the first phase of the model proposed sought to achieve by focusing on the simplification of the assembly process. To optimize the sequence of the products for clients like Tottus, Makro, and Supesa, a Python-based model was created which accounted for the geometry and weight factors of each pallet. The algorithm considered factors such as: the width, length, maximum height of the pallet, weight restrictions, and the number of codes per pallet bound limits.

After the solution was validated through controlled test runs, a comprehensive operational procedure was created which included a user manual for the Python program alongside a manual for physical assembly broken down into sequential steps. To enhance warehouse efficiency, the model's instructions contained unambiguous guidelines regarding the type, quantity, and placement of the products which need to be assembled.

With the procedure set in place, the logistics staff was instructed on the semi-automatic stretch-wrapping machine alongside the new digital interfaces. These lessons combined both the theoretical and practical elements to help bolster the grasp of systematic approaches, led by a palletization expert.

A system focused on continuous improvement was developed, which included the inspection of pallet assembly quality along with spatial auditing, time measurement, and the collection of feedback. This system enabled feedback from operations to be integrated for system refinement in combination with continual improvement.

Figure 2

b) Autonomous Maintenance: Ensuring Equipment Availability

The second stage of the solution dealt with the downtime associated with the breakdown of the semi-automatic stretch-wrapping machine. As part of the total productive maintenance (TPM) approach, the autonomous maintenance pillar was implemented, transferring some basic maintenance tasks to the equipment operators and reducing external dependency, thereby fostering employee engagement with the assets on a deeper level.

The initiative began with checking some critical parts like the belts, motors, stretching systems, and the rotating chains. This assessment was used to set maintenance tasks from cleaning, lubricating, and checking components. These tasks were integrated into a coherent program for autonomous maintenance.

Step-by-step guides were created from maintenance checklists, which outlined all necessary parts and actions to complete the task. Recommended materials were also prescribed, such as lubricating oils SAE 20 ISO VG50 and spray lubricants SAE 50 ISO VG300, which meet the manufacturer's requirements. Work instructions were structured in a way to define each step of maintenance in clear and simple language supplemented by illustrations. Afterward, the instructional sessions were conducted by the equipment supplier's certified mechanical-electrical technician who ensured factory compliance.

Periodic evaluations of machines, tracking of failures, and the incorporation of feedback schemes from operators drove continuous improvement efforts. This resulted in increased Mean Time Between Failures (MTBF) for equipment ENV001 from 119.5 hours to 361 hours, and for ENV002 from 132.4 hours to 304.5 hours. MTTR (Mean Time To Repair) also improved and reduced from 2.81 hours to 1.4 hours for ENV001 and from 2.71 hours to 1.5 hours for ENV002. These improvements provided additional evidence to the enhancement in reliability and maintainability of the equipment.

During this phase, the critical components of the stretch-wrapping machine were identified and evaluated through visual inspections carried out by the operating staff. Based on this assessment, an autonomous maintenance procedure was developed, focusing on proper cleaning and lubrication of the equipment. All operators were trained in the tasks outlined in the procedure, as well as in the correct use of the machine, through sessions led by a mechanical-electrical specialist from the equipment supplier, ensuring the effectiveness of the training. Table 1 shows the types of failures detected in the stretch-wrapping machines during the inspection process, which were considered in the design of preventive maintenance activities.

Table 1 : Types of Failures in Wrapping Machines

Code	Detected Failure
A	Improper operation of limit switches
B	Emergency button activated
C	High temperature in the motor electrical junction box
D	False contact in limit switch
E	Lack of lubrication in gear wheel
G	Lack of lubrication in the rotating platform chain
H	Lack of lubrication in bearings
I	Lack of lubrication in drive chain
J	Fault in proximity switches

During this phase, operators inspected the key components of the semi-automatic stretch-wrapping machine to assess their condition. Based on the findings, an autonomous maintenance procedure was established, focusing on cleaning and lubrication tasks. Training was delivered by a specialist from the equipment supplier to ensure proper execution. Figure 3 shows the stretch-wrapping machine installed at the distribution centre, highlighting the operational setting where the maintenance activities were implemented..

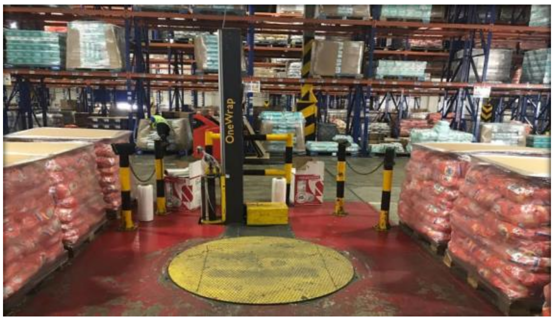


Figure 3 : Semi-Automatic Wrapping Machine in the Case Study Distribution Centre

c) Poka Yoke and Engineering Controls: Precision and Safety in the Truck Assembly Line

This phase concentrates on trying to remove errors in the assembly work of internal structures of double-deck trucks. It also looks at minimizing safety incidents during the assembly process. The employing of Poka Yoke, in tandem with engineering controls, allowed both heuristic and structural mechanisms to be implemented visually, mechanically, and preventively.

Bar supports were positioned along the truck rails with the intent to act as stoppers, visually and physically aiding accurate spacing during structural bar insertion. Also, a rotating holder was constructed with slots placed vertically to facilitate easy indexing and quick retrieval of the structural bars.

Compliance with ergonomics and general safety standards was maintained when updating with these devices in the assembly procedures. To further investigate the spectrum of risk, an IPERC matrix was applied which diagnosed hazards of cuts, impacts, and slips for the task of bar-handling.

According to the analysis, further engineering controls were placed into action. Enhancements included affixing 4 mm anti-impact material to the bar edges, applying colored tape for visibility, and installation of rail locks to avoid pallets slipping during movement. Cumulatively, these modifications encouraged a better operating environment for the operators.

The effects were observed immediately and were found to be substantial. Internal structure assembly time shrunk from 2.84 to 2.06 hours per truck, demonstrating a 27.71% reduction. Furthermore, the number of reported organizational safety incidents pertaining to this task was *none*, proving the implemented measures have worked.

Figure 4 : Poka Yoke Implementation

The Poka Yoke and IPERC tools were implemented to eliminate errors in the assembly of the internal structure of double-deck trucks and to reduce associated safety incidents. Figure 4 shows the application of the Poka Yoke system, which consisted of installing metal stoppers marked along the rails to guide the operator in the precise placement of the bars, as well as a numbered rotating metal holder that facilitates their identification and organized use. These actions, together with risk control through IPERC, helped reduce unproductive time caused by incorrect assembly and unsafe conditions, directly contributing to the improvement of logistics performance and compliance with the OTIF indicator.

To reduce the risk of cuts, impacts, and slippage during the internal assembly of double-deck trucks, engineering controls were implemented. These included covering the edges of metal bars with 4 mm anti-impact material, applying reflective yellow tape for signaling, and adding rail locks to prevent pallet slippage. **Figure 5** shows this implementation, highlighting the applied measures and operator involvement. These actions improved both safety and the efficiency of the logistics process.

Figure 5 : Engineering Controls Implementation

The initial phase concentrated on improving the pallet assembly activities for Out log by applying an optimization model created in Python, which calculated an optimized sequence of boxes for every pallet. An accompanying Standard Operating Procedure (SOP) was created alongside a user guide for the model's software. Furthermore, all operators were instructed theoretically and practically, which included the proper operation of the stretch-wrapping machine. This optimization alone achieved a 28.38% savings in assembly time - from 6.20 to 4.44 hours per pallet - by eliminating rework and downtime.

Figure 6 shows an example of the output format for one of the optimized pallets for client Supesa. It specifies the product level with alphanumeric descriptors such as description, code, quantity, warehouse, LPN, and delivery numbers, which encompass the release numbers linked to the outbound shipment. This is one of the outputs from the optimization model and served as a cognitive aid for the warehouse personnel in the actual construction of pallets. With this output, the criteria for loading became uniform while subjectivity errors were minimized.

Supesa - Shipment 1

Número de paleta: 0007
Delivery: , 707739533

Tipo	Código	Descripción	Cantidad	Local	LPN	Delivery
CAMA 1	80701454	DOWNY BRISA FRESCA Mx&EXP 700MLX9IT P&B	18	FLUJO	500000080117710007	707739533
CAMA 2	80689208	DOWNY FLORAL Mx & EXP 700MLX9IT	18	FLUJO	500000080117710007	707739533
SALDO	80689208	DOWNY FLORAL Mx & EXP 700MLX9IT	15	FLUJO	500000080117710007	707739533
SALDO	80689175	AYUDIN LIMON Y SABILA 850GRX12IT	5	FLUJO	500000080117710007	707739533
SALDO	80684834	AYUDIN LIQ LIMA LIMON 1200MLX12IT	1	FLUJO	500000080117710007	707739533
SALDO	80695671	Downy Floral Mx&EXP 4.8Lx2IT P&B	1	FLUJO	500000080117710007	707739533
SALDO	80349764	ARIEL TOD POUCH MT 1200MLX8IT EX	1	FLUJO	500000080117710007	707739533
SALDO	80682364	AYUDIN LIMON Y SABIL 170GRX24IT	1	FLUJO	500000080117710007	707739533
SALDO	80349790	ARIEL DP LIQ MT PACK GREEN 4LX2IT EX	3	FLUJO	500000080117710007	707739533

Figure 6 : Format of Assembly By Pallet

In addition, the results stemming from the model's application are illustrated in Figure 7 for the warehouse zone where fully prepared pallets are presented. The homogeneous stacking, aligned edges, and proper placement of separator boards on top of the pallets showcases order that improves both the wrapping and labeling processes, enhances transport stability, and in turn, greatly alleviates poorly distributed load logistics incidents.

Figure 7 : Supervision of Pallet Assembly

D. Results

Table 2 presents the performance of the main indicators after the validation of the operations management model based on Lean Manufacturing and TPM. The OTIF indicator reached 97.05%, surpassing the expected standard. Likewise, the MTBF increased to 361 hours, demonstrating higher operational reliability, while the MTTR was reduced to 1.4 hours, optimizing repair times. No safety incidents were recorded, reflecting improvements in the work environment. In addition, the product pallet assembly time decreased to 4.44 hours, and the assembly time for the internal structure of double-deck trucks was reduced to 2.06 hours. These results validated the effectiveness of the proposed model in enhancing operational efficiency and improving the service level within the case study company.

Table 2 : Indicators After Model Implementation

Indicator	Unit	As-Is	To-Be	Results	Variation
OTIF	%	91.90%	>95%	97.05%	5.60%
MTBF	hours	119.5	>300	361	202.09%
MTTR	hours	2.81	<1.50	1.4	-50.18%
Safety incidents	incidents	22	0	0	-100.00%
Product pallet assembly time	hours	6.2	<5	4.44	-28.39%
Double-deck truck internal structure assembly time	hours	2.84	<2.10	2.06	-27.46%

V. DISCUSSION

The result of the study validates the effectiveness of the Lean-TPM model in optimizing the logistics processes of a medium sized distribution company of mass consumption goods. The OTIF metric improvement of 91.9% to 97.05% supports Džubáková and Kopták's conclusion that standardization of processes using Lean practices greatly improves service and market responsiveness [17]. In the same manner, employing optimization algorithms for pallet assembly follows Zumarán's approach regarding fruit logistics where supply chain performance was improved through standardized work and routing algorithms [18]. Furthermore, the addition of autonomous maintenance along with failure control boosted MTBF by over 200% and reduced MTTR by over 50%, reflecting Bragança and Costa's assertion on the impact of TPM's operational effectiveness and culture of continuous improvement [19].

Even with favorable outcomes, this study has some restrictions which need to be addressed while interpreting its findings. The model was only validated in one medium-sized cleaning and hygiene company based in Lima, which limits the scope of the study to extrapolate its findings to other sectors or regions. It's also important to note that the timeframe for implementing the model was relatively short (four months), and therefore, the assessment in operational sustainability over a longer period was not possible. In addition, some indicators such as employees' active participation or transformation of organizational culture were not measured, despite the perceptions of qualitative improvement during training sessions and post-evaluations.

The modular structure of the Lean-TPM model allows for tailored and incremental application of work standardization, autonomous maintenance, and Poka Yoke coupled with engineering controls. It illustrates that attainment of operational improvements is possible with high efficiency and minimal financial investment, provided that a systematic and participatory approach is employed. In addition, the internal capability development as well as organizational resilience is enhanced during the economic downturns by upskilling operational and technical personnel as they refine their own processes throughout the work.

There is an open invitation to consider implementing the model within different businesses at varying locations and in different industries to test its validity and check for its flexibility in different operational contexts. Extending the monitoring period would aid in assessing the long-term impacts of the model on the KPIs of employee retention, organizational culture, and customer satisfaction. Integrating advanced digital technologies, such as IoT sensors or smart dashboards, to automate monitoring of critical variables would enrich the ability to support real-time decision-making. Finally, other researchers can examine incorporating the Lean-TPM model with approaches of environmental sustainability focused on determining the impact on the resources consumed as well as the ecological footprint of logistics operations.

VI. CONCLUSION

The research validates the effective results from the integration of Lean Manufacturing and Total Productive Maintenance tools into a customized operations management framework for a medium-sized distribution company. The results yielded remarkable improvements in primary metrics such as a 5.15% OTIF increase, MTBF growth by over 200%, and MTTR reduction by 50%. In addition, the model's ability to eliminate safety incidents and further optimize truck loading and pallet assembling times showcased its real-world adaptability to operational variability optimization.

This research is particularly important because it focuses on a gap in the industrial engineering field which is the use of Lean-TPM practices in distribution companies, especially in the context of Latin America. The study contributes to empirical knowledge while addressing the high contraction opportunity demand from adaptable efficiency paradigms by targeting a context neglected by dominant literature. It demonstrates the adept application of lean-based frameworks to service-centric supply chains with time and accuracy expectations.

The developed model enhances the body of knowledge by presenting a modular and repeatable structure that integrates standard operating procedures, autonomous maintenance, and error-proofing methodologies within a continuum of ongoing refinement cycles. It advances existing theory by showing the interaction of these elements not as fragments, but as components of a cohesive system yielding sustained operational improvements. This study, therefore, fulfills the empirical gap by providing managers and industry professionals actionable strategies while also bridging the conceptual gap between academia and practice.

It is recommended that further research explore the model's applicability for scalability by testing it in large-scale or different industry contexts and assessing its flexibility in relation to time. The addition of some features could enhance the functional capabilities of the model, such as IoT-based surveillance systems or real-time dashboards. Additionally, the integration of operational productivity metrics with environmental sustainability parameters could create other responsible industrial development aligned research opportunities concerning world trends.

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