Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF6.20250008
Published: April 8, 2025

Developing a Maintenance Management Model for Service Level Optimization: A Case Study in Peruvian Heavy Goods Transport SMEs

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Abstract

The study addressed critical inefficiencies in heavy goods transport SMEs, focusing on improving service levels and operational reliability. It identified challenges such as low On-Time In Full (OTIF) rates and high equipment failure rates, which significantly impacted service quality. The proposed research integrated Total Productive Maintenance (TPM) principles and Process Management into a unified maintenance model, emphasizing planned and autonomous maintenance strategies. Key findings revealed measurable improvements: OTIF increased by 7.24%, fuel shortages dropped by 50%, and damaged load indices decreased by 23.20%. These outcomes underscored the model's potential to enhance resource utilization and service reliability. This research demonstrated the relevance of systematic maintenance strategies in aligning operational activities with organizational goals, fostering efficiency and sustainability. By addressing specific gaps in existing maintenance practices, the study provided a replicable framework applicable across similar contexts, offering actionable insights for enhancing operational metrics in resource-constrained environments. It significantly contributed to bridging knowledge gaps in maintenance management for SMEs, particularly in the transport sector. Future investigations should explore integrating advanced digital tools, such as IoT-based monitoring systems, to expand predictive maintenance capabilities. Moreover, cross-sectoral comparative analyses could enrich understanding of the model's adaptability and limitations. This research sets the groundwork for ongoing advancements in SME maintenance management.

Keywords
Maintenance Management, Total Productive Maintenance, Service Level Optimization, Heavy Goods Transport SMEs.

1. Introduction

The importance of the small and medium-sized enterprises (SMEs) sector in heavy goods transport is undeniable, both globally and in specific contexts such as Latin America and Peru. This sector is not only crucial for the economy, but also plays a vital role in the global supply chain. According to a study by Al-Haddad et al. (Al Haddad et al. 2019), SMEs generate a significant proportion of employment and contribute to economic growth in developing countries. In Latin America, SMEs are estimated to account for approximately 99% of all enterprises and generate around 60% of jobs (Johnson & Schaltegger 2015). In Peru, the heavy goods transport sector is essential, as the country depends heavily on this type of transport for the distribution of goods and raw materials throughout its extensive territory. However, despite their relevance, transport SMEs face significant challenges that limit their ability to operate efficiently and competitively.

One of the most critical problems faced by these SMEs is the low level of service, which can be measured through the On-Time Delivery Rate (OTIF Rate). This indicator reflects the availability of transport units and efficiency in loading and unloading goods. The low availability of transport units results in high rates of inadequate load, which in turn generates high failure rates in critical components such as brakes, suspension and engine. In addition, errors in fuel supply calculations can lead to operational inefficiencies and additional costs. According to a study by Johnson and Schaltegger (2015), lack of proper maintenance and inefficient management of resources are factors that contribute to these problems, affecting the profitability and sustainability of transport SMEs.

Addressing these issues is of paramount importance as operational efficiency and quality of service are critical to competitiveness in the transport sector. The implementation of methodologies such as Total Productive Maintenance (TPM) and Process Management can be key to improving the availability of transport units and reducing failure rates. Research by Xiang and Feng (2021) highlights that the implementation of TPM not only improves equipment efficiency, but also fosters a proactive maintenance culture among workers. This is particularly relevant for SMEs, which often lack the resources to make significant investments in infrastructure and technology.

Despite the growing attention given to quality management and maintenance in SMEs, there is a knowledge gap in the literature that needs to be addressed. Many studies have focused on large companies, leaving SMEs in the background (Karadağ, 2015). The proposed research aims to close this gap by developing a production model that integrates TPM tools, such as Autonomous and Planned Maintenance, with Process Management. This approach not only seeks to improve operational efficiency, but also provides a framework that enables SMEs to adapt to changing market demands and improve their competitiveness (Samadhiya et al. 2023). Existing literature suggests that the adoption of these methodologies can result in significant improvements in SME sustainability and performance (Borrajo et al. 2012).In conclusion, the SME sector of heavy goods transport is an essential component of the global and local economy, especially in Latin America and Peru. However, it faces significant challenges that require urgent attention. The implementation of maintenance and management methodologies can be the key to improving the efficiency and sustainability of these companies, and the proposed research seeks to contribute to this objective by addressing existing gaps in the literature.

2. Literature Review

Literature review on maintenance and distribution in small and medium-sized enterprises (SMEs) of heavy load transport is critical to understanding how maintenance methodologies can optimize operational efficiency and reduce costs. In this context, various maintenance methodologies will be explored, including Total Productive Maintenance (TPM), Autonomous Maintenance, Preventive Maintenance, Process Management and Process Standardization. Each of these approaches offers unique strategies that can be applied in the heavy-duty transport sector, helping to improve the operational effectiveness and sustainability of these companies.

2.1 Total Productive Maintenance (TPM) methodology in Heavy Load Transport SMEs

Total Productive Maintenance (TPM) has been implemented in various industries as a strategy to improve the effectiveness of equipment and reduce downtime. According to Bataineh et al. (2019), TPM is a methodology that involves all employees in the maintenance process, which fosters a culture of shared responsibility and improves productivity. This approach has proven effective in reducing operational costs, as maintenance can account for a significant portion of total costs in some industries (Bataineh et al. 2019). In addition, studies such as Gwangwava et al. Gwangwava et al. (2021) suggest that the implementation of TPM in SMEs can lead to significant improvements in operational efficiency by integrating maintenance practices into organizational culture. Research by Modgil and

Sharma Modgil & Sharma (2016) also highlights that TPM not only improves product quality but also optimizes resource use, which is crucial for SMEs in heavy freight transport operating with tight margins.

2.2 Autonomous maintenance in the transport sector

Autonomous Maintenance is another relevant methodology that allows machine operators to take on basic maintenance responsibilities, which can increase efficiency and reduce the reliance on skilled personnel. According to Muchiri et al. (2011), Autonomous Maintenance empowers workers by enabling them to perform preventive and corrective maintenance tasks, resulting in greater availability of equipment. This approach is particularly beneficial in the heavy-duty transport sector, where the availability of vehicles and equipment is critical to meeting delivery deadlines. Research by Yang & Yang (2023) indicates that employee involvement in Autonomous Maintenance not only improves morale, but also contributes to early identification of problems, which can prevent costly failures. Furthermore, the study by Reyes et al. (2018) shows that the implementation of Autonomous Maintenance practices can be a key factor in achieving continuous improvement in service quality in transport SMEs.

2.3 Preventive Maintenance: Strategies and Benefits

Preventive Maintenance is a strategy that focuses on performing scheduled maintenance to prevent failures before they occur. According to Gopalakrishnan et al. (2020), this methodology is essential for ensuring business continuity in SMEs of heavy freight transport where downtime can result in significant losses. Research by Supsomboon & Hongthanapach (2014) supports this claim, demonstrating that the implementation of a Preventive Maintenance program can increase equipment availability and improve operational efficiency. In addition, the study by Hinrichs Hinrichs (2023) highlights that digitisation of maintenance through computerized maintenance management systems can facilitate the planning and execution of preventive maintenance, Enabling SMEs to better manage their resources and reduce costs. The combination of these practices can result in a significant reduction in maintenance costs and an increase in overall productivity.

2.4 Process management in maintenance

Process Management is an approach that seeks to optimize workflows within an organization, and its application in maintenance can lead to a significant improvement in operational efficiency. According to Telek (Telek 2023), the integration of process management into maintenance practices enables SMEs to identify bottlenecks and areas for improvement, resulting in a more fluid operation. Research by Sigsgaard et al. (2021) also suggests that process management can help align maintenance activities with the strategic objectives of the organization, which is essential for SMEs looking to grow in a competitive market. In addition, the study by Macchi et al. (2014) emphasizes the importance of process management in creating intelligent e-maintenance platforms that can improve decision-making and operational efficiency in SMEs in heavy cargo transport.

2.5 Standardization of Maintenance Processes

Finally, process standardisation is a critical aspect that can contribute to continuous improvement in the SME heavy-duty transport. Research by Jain et al. (2014) indicates that standardization of maintenance practices not only improves quality and consistency of service, but also facilitates employee training and the implementation of new technologies. According to the study by Tewari (2017), standardization allows organizations to establish clear metrics for evaluating maintenance performance, which is essential for continuous improvement. In addition, the work of Felice et al. (2014) suggests that process standardization can be a key factor for integrating advanced technologies into maintenance practices, which can result in greater efficiency and cost savings. Taken together, these methodologies provide a strong framework for SMEs in heavy-duty transport to optimize their operations and improve their competitiveness in the market.

In conclusion, the implementation of maintenance methodologies such as TPM, Autonomous Maintenance, Preventive Maintenance, Process Management and Process Standardisation can have a significant impact on the operational efficiency and sustainability of SMEs in heavy goods transport. These strategies not only help to reduce costs and improve equipment availability, but also foster a culture of continuous improvement and shared responsibility among employees. As the heavy-duty transport sector continues to evolve, the adoption of these methodologies will be essential for SMEs to remain competitive and respond to changing market demands..

3. Methods

3.1 Basis of the Proposed Model

In Figure 1, the integrated maintenance model is presented, combining Total Productive Maintenance (TPM) principles with process management to enhance operational efficiency and reliability. This model is structured around three interdependent pillars: process management, planned maintenance, and autonomous maintenance. Process management provided a systematic framework to align maintenance activities with organizational goals, ensuring that all efforts contributed to overarching strategic objectives. Planned maintenance focused on implementing preventive and predictive strategies to minimize equipment downtime, reduce unexpected failures, and optimize resource allocation. Autonomous maintenance empowered workers to take responsibility for routine upkeep and early detection of potential issues, fostering a culture of accountability and collaboration. The synergy between these components was designed to promote continuous improvement, reduce inefficiencies, and enhance overall equipment reliability. This approach emphasized proactive measures and integration across different organizational levels, making it adaptable to various operational contexts while ensuring sustainable long-term performance.

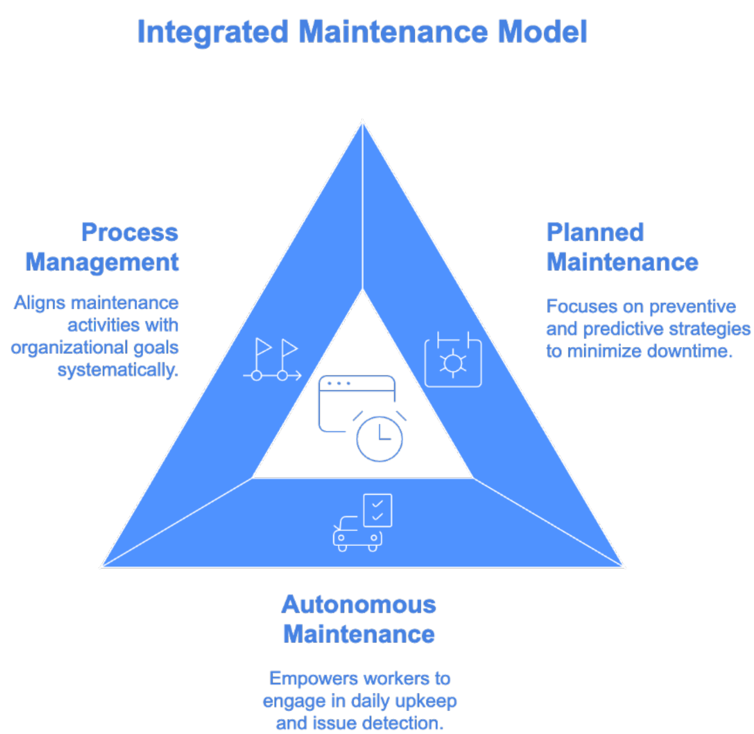

Figure 1. Proposed Model

3.2 Description of the model components

The proposed integrated maintenance model represents a robust framework aimed at addressing critical inefficiencies in organizational maintenance processes. Built upon the foundational principles of Total Productive Maintenance (TPM) and process management, this model seeks to optimize resource utilization, enhance equipment reliability, and reduce operational downtime. Its systematic structure aligns maintenance strategies with organizational objectives, ensuring a cohesive approach to long-term operational sustainability. By focusing on the complementary roles of planned maintenance, autonomous maintenance, and process management, the model provides a comprehensive solution that bridges gaps in existing maintenance practices and contributes significantly to the literature on operational management in industrial engineering.

Process Management: Aligning Maintenance with Organizational Goals

At the core of the model lies the philosophy of process management, which served as the guiding framework for integrating maintenance activities into the organization's strategic goals. This component focused on establishing a structured approach to defining, monitoring, and continuously improving maintenance-related processes. The implementation began with a thorough analysis of existing workflows to identify inefficiencies and bottlenecks that hindered operational performance. Maintenance tasks were mapped and standardized to ensure consistency across all organizational levels. The integration of process management principles enabled the alignment of daily maintenance activities with broader performance objectives, such as reducing unplanned downtime and improving equipment availability. By fostering a culture of accountability and systematic problem-solving, this stage laid the foundation for a proactive maintenance environment capable of adapting to dynamic operational demands.

Planned Maintenance: Preventive and Predictive Strategies for Sustained Performance
The planned maintenance component emphasized the importance of adopting preventive and predictive strategies to minimize equipment failures and unplanned downtime. This stage involved the development and implementation of maintenance schedules based on equipment usage patterns and historical performance data. The preventive aspect focused on routine inspections, lubrication, and part replacements, ensuring that potential issues were addressed before escalating into significant failures. Predictive maintenance, on the other hand, leveraged condition-monitoring techniques such as vibration analysis and thermal imaging to detect anomalies early. These strategies not only reduced the frequency of breakdowns but also optimized the allocation of maintenance resources. Additionally, the planned maintenance framework included performance audits to evaluate the effectiveness of implemented strategies, enabling continuous refinement of maintenance schedules and processes. This systematic approach ensured the long-term reliability of critical equipment while maintaining operational efficiency.

Autonomous Maintenance: Empowering Workers for Operational Excellence
The autonomous maintenance pillar aimed to empower frontline workers by involving them directly in routine maintenance activities and early issue detection. This component was designed to foster a sense of ownership among employees, encouraging active participation in maintaining equipment health. Training programs were conducted to equip workers with the necessary skills to perform basic maintenance tasks, such as cleaning, lubrication, and visual inspections. These activities not only improved equipment performance but also enhanced the workers' ability to identify and report potential issues promptly. Visual management tools, such as checklists and indicator boards, were introduced to streamline the execution and monitoring of autonomous maintenance tasks. This approach created a feedback loop between workers and supervisors, facilitating immediate corrective actions and reinforcing a culture of collaboration and accountability. The integration of autonomous maintenance into the broader model ensured that maintenance responsibilities were shared across all organizational levels, promoting operational resilience.

Synergy and Integration: A Holistic Framework for Continuous Improvement
The true strength of the proposed model lies in the seamless integration of its three components—process management, planned maintenance, and autonomous maintenance. Each element was designed to complement the others, creating a cohesive system that addressed maintenance challenges from multiple angles. Process management provided the overarching structure and alignment needed to coordinate efforts effectively. Planned maintenance ensured that equipment reliability was maintained through systematic and data-driven interventions. Autonomous maintenance engaged workers in the upkeep of equipment, fostering a proactive and collaborative maintenance culture. Together, these components formed a robust framework for continuous improvement, enabling the organization to adapt to changing operational needs while maintaining high levels of performance and reliability.

In conclusion, the integrated maintenance model proposed in this study offers a transformative approach to addressing maintenance inefficiencies and enhancing operational performance. By combining the principles of TPM with process management, the model provides a comprehensive solution that is both practical and scalable across various industrial contexts. Its emphasis on proactive strategies, worker empowerment, and systematic process alignment ensures that maintenance activities contribute directly to achieving organizational objectives. The model's adaptability and focus on continuous improvement position it as a valuable tool for organizations seeking to enhance their competitiveness and sustainability in an increasingly dynamic industrial landscape.

3.3 Model Indicators

Specialized metrics were developed to monitor and evaluate performance throughout the case study to assess the impact of the maintenance management model that incorporates TPM and Process Management tools. These metrics provided a reliable basis for the review of critical components of maintenance management in a heavy-duty SME.

This methodical approach allowed for a thorough review of the critical performance indicators, thus ensuring accurate monitoring and promoting continuous improvements in the maintenance and distribution processes.

OTIF (On Time in Full):
This indicator measures the percentage of deliveries completed both on time and in full as planned, reflecting the overall reliability of the distribution process.

$$OTIF = (On - Time\ Delivery\ Rate \times Complete\ Delivery\ Rate) \times 100 \quad (1)$$

On-Time Delivery Rate:
It evaluates the proportion of deliveries that were successfully completed on time, helping identify scheduling and logistical bottlenecks.

$$On - Time\ Delivery\ Rate = \left(\frac{Number\ of\ On - Time\ Deliveries}{Total\ Deliveries}\right) \times 100 \quad (2)$$

Availability Rate:
This metric assesses the proportion of operational time to total time, indicating the effectiveness of maintenance activities.

$$Availability\ Rate = \left(\frac{Total\ Operating\ Hours - Downtime\ Hours}{Total\ Operating\ Hours}\right) \times 100 \quad (3)$$

Fuel Shortage Percentage:
It calculates the percentage of orders impacted by fuel shortages, which highlights inefficiencies in fuel supply management.

$$Fuel\ Shortage\ Percentage = \left(\frac{Number\ of\ Orders\ with\ Fuel\ Shortages}{Total\ Orders}\right) \times 100 \quad (4)$$

Damaged Load Index:
This indicator represents the percentage of deliveries containing damaged goods, a critical factor in quality control and customer satisfaction.

$$Damaged\ Load\ Index = \left(1 - \frac{Number\ of\ Complete\ Deliveries}{Total\ Deliveries}\right) \times 100 \quad (5)$$

4. Validation

4.1 Validation Scenario

The validation scenario was conducted within a case study involving a company dedicated to the transportation of heavy cargo for import and export operations. This organization primarily serves port terminals, customs warehouses, and general storage facilities across local and national destinations. It operated with a fleet of five owned trucks, complemented by subcontracted vehicles when demand required. The company's annual revenue reached approximately 500,000 PEN, and it maintained strategic partnerships with key warehousing providers. These collaborations played a critical role in supporting its logistical operations. The research aimed to address challenges within its distribution process, specifically focusing on service level improvements. The company's processes were characterized by their reliance on resource allocation and coordination activities, which were mapped using SIPOC diagrams for clarity. These maps were instrumental in understanding the flow of operations and pinpointing areas requiring optimization to meet customer expectations effectively.

4.2 Initial Diagnosis

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In Figure 2, the problem tree illustrates the diagnostic analysis conducted to identify the reasons and root causes behind the low service level in the distribution process. The case study revealed a technical gap, with an OTIF rate of 75%, falling short of the industry standard of 90%. This deficiency resulted in an economic impact of 83,567 PEN per year, equivalent to 16.7% of the company's annual revenue. The primary issue was attributed to low unit availability, accounting for 58% of the problem, and a high rate of improper loading, which contributed 22%. Further investigation identified root causes, such as a 38% failure rate in braking, suspension, and engine systems, and a 20% occurrence of errors in fuel supply calculations. Additionally, damaged goods during transport represented a 22% contribution to improper loading issues. This structured diagnostic approach aimed to address these inefficiencies and align operational performance with industry standards.

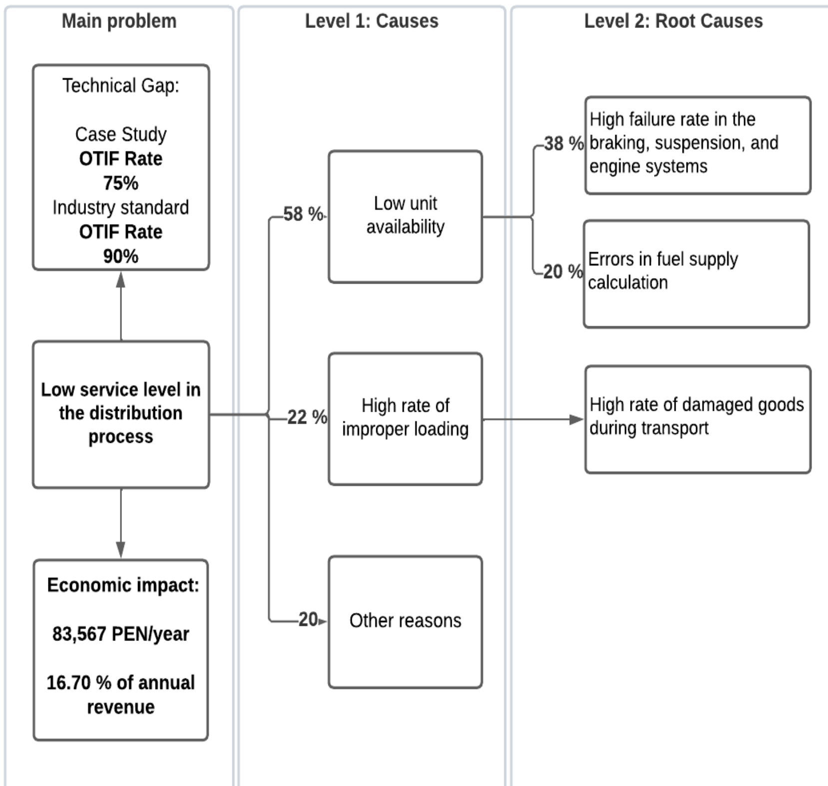

Figure 2. Problem Tree

4.3 Implementation of the model in the case study

The proposed solution was meticulously designed to address the low service level in the distribution process identified in the case study. This design integrated process management principles with key components of the Total Productive Maintenance (TPM) framework, including planned and autonomous maintenance. The aim was to optimize operations by reducing inefficiencies, minimizing errors, and ensuring timely and complete service deliveries. The structured implementation of these methodologies was guided by detailed analysis and supported by quantitative data to evaluate their effectiveness.

Design of the Planned Maintenance

The planned maintenance strategy focused on minimizing unexpected vehicle failures, which accounted for 28% of service interruptions. A Failure Modes and Effects Analysis (FMEA) was conducted, identifying high-risk components such as braking systems, suspension, and engines. This analysis informed the development of detailed technical sheets for each vehicle, specifying maintenance frequencies and procedures. For instance, brake system checks were scheduled every 15 days, while engine diagnostics were performed monthly. A centralized maintenance schedule was created, incorporating manufacturer recommendations and operational requirements, ensuring consistency and precision. To monitor progress, logbooks were standardized, capturing key metrics such as maintenance completion rates, which improved by 12% post-implementation. A checklist system was also introduced to verify compliance, ensuring all tasks were completed according to the plan.

The figure 3 presents the technical data sheet for the vehicle identified as SNF-01, a Freightliner M2 112 Tractor. The sheet provides detailed specifications, including dimensions, weights, capacities, and technical components. The vehicle measures 7.14 meters in length, 2.495 meters in width, and 3.512 meters in height, with an internal cargo box measuring 4.18 meters in length, 2.2 meters in width, and 1.2 meters in height. It has a gross weight of 19,481 kg, a maximum load capacity of 27,500 kg, and a fuel tank capacity of 680 liters. The engine is a Mercedes-Benz MBE 4000 model with 410 HP, powered by diesel. The transmission is a Fuller FS-6406N manual system with six speeds. The braking system is fully pneumatic with ABS technology, featuring drum brakes for both front and rear. Additional details include a bi-disc clutch with a diameter of 14 inches, Vari-Rate pneumatic rear suspension with a capacity of 23,500 pounds, and hydraulic steering (TRW TAS 85). The vehicle is equipped with six tires of size 11.00 x 22.5.

R-TEC- 01 FICHA TÉCNICA

Vehículo
SNF - 01

MARCA	Freightliner
MODELO	M2 112 Tractor

DIMENSIONES DE UNIDAD	
Largo (m)	7.14
Ancho (m)	2.495
Altura (m)	3.512

DIMENSIONES DE CAJA INTERNA	
Largo (m)	4.18
Ancho (m)	2.2
Altura (m)	1.2

PESOS Y CAPACIDADES	
Peso Bruto	19,481 kg
Cant. Pasajeros	2
Capacidad máx.	27,500 kg
Capacidad tanque	680 L

MOTOR	
Marca	Mercedes-Benz
Modelo	MBE 4000
Potencia máxima	410 HP
Tipo combustible	Gasoil

FRENOS	
Tipo	100% neumático
Seguridad	ABS
Delanteros/Posteriores	Tambor

TRANSMISIÓN	
Marca	FULLER
Modelo	FS-6406N
Tipo	Manual 6x4
Velocidades	06 Vel

EMBRAGUE	
Tipo	Bi-Disco
Diametro	14"

DIRECCIÓN	
Marca	TRW
Referencia	TAS 85
Tipo	Hidráulica

SUSPENSIÓN TRASERA	
Modelo	Vari-Rate
Marca	Freightliner
Tipo	Neumática
Capacidad	23,500 lb

SUSPENSIÓN DELANTERA	
Modelo	Vari-Rate
Marca	Freightliner
Tipo	Neumática
Capacidad	14,000 lb

RUEDAS	
Dimensión	16
Medidas	11,00 x 22,5
Cantidad	6

Figure 3. Vehicle data sheet SNF – 01

Figure 4 presents the Failure Mode and Effects Analysis (FMEA) for the SNF-01 truck, focusing on the braking and suspension systems. The braking system exhibited two primary failure modes: air leakage in the pipes and brake pad wear. Air leakage led to pressure loss, resulting in braking failure and potential accidents, with a high Risk Priority

Number (RPN) of 432 due to its severity, frequency, and detectability. Brake pad wear, without control measures in place, also posed significant risks, with an RPN of 405.

The suspension system highlighted two failure modes: worn shock absorbers and spring breakage. Worn shock absorbers caused increased wear on suspension components and abnormal noises, with an RPN of 252. Spring breakage led to vehicle imbalance and uneven tire wear, with an RPN of 175. Current control measures included visual and auditory inspections for the suspension system, while no controls were present for the braking system, emphasizing the need for immediate corrective actions.

ANÁLISIS DE MODO Y EFECTO DE FALLAS									
Sistema	**Función**	**Falla funcional**	**Modo falla**	**Efecto de falla**	**Control actual**	**Detección**	**Gravedad**	**Frecuencia**	**IPR**
Frenado	Disminución de velocidad y detección de vehículo	Deficiente frenado	Fuga de aire por cañerias	Falta de presión en los frenos, falla de frenos y posible accidente	No hay control	6	9	8	432
			Desgaste de zapatas	No permite frenar de manera correcta, falla de frenos y posible accidente		5	9	9	405
Suspensión	Estabilidad en la conducción del vehículo	Falla en suspensión	Amortiguadores desgastados	Se golpean los muelles de suspensión, mayor desgaste de las piezas, ruidos por golpes entre piezas	Revisión visual y auditiva	6	6	7	252
			Ruptura de muelles	Desgaste del amortiguador, se desnivela el vehículo, desgaste anormal de neumáticos		5	5	7	175

Figure 4. Analysis of mode and effect of failure of theSNF-01 truck

Figure 5 outlines the preventive maintenance schedule for the SNF-01 truck, detailing specific actions, components, and frequencies for each system. The transmission system requires oil filter cleaning every 20,000 kilometers. The braking system includes monthly visual inspections of brake pads and semiannual checks for air pipe cleaning. Suspension components, such as shock absorbers and control arms, undergo inspections every six months for corrosion and deformation. The motor requires bimonthly visual checks of the thermostat and seals, alongside oil filter cleaning. Tire maintenance includes monthly mechanical scraping to ensure wear is within acceptable limits. The steering system mandates semiannual inspections of steering bars, gearboxes, and hoses for wear and proper alignment. Electrical components, including the battery and alternator, are inspected annually for electrical connection issues and charge levels. The operations coordinator's assistant oversees all tasks to ensure compliance, guaranteeing the vehicle's operational reliability and extending its service life.

Cronograma de mantenimiento preventivo						
Sistema	**Pieza de la unidad**	**Acción**	**Tipo**	**Responsable**	**Semana Inicial**	**Periocidad**
Transmisión	Filtro de aceite	Limpieza de filtro	Limpieza	Asistente de coordinador de operaciones	1	Cada 20 mil KM
Frenos	Cañerías de aire	Inspección y limpieza de tuberías	Inspección			Mensual
	Zapatas	Inspección visual y medición de grosor	Inspección			
Suspensión	Amortiguadores	Inspección visual en busca de fugas	Inspección			Semestral
	Brazos de control	Inspección en busca de corrosión	Inspección			
	Conexiones y pernos	Verificar ajuste y estado	Inspección			
	Muelles	Inspección para detección de deformaciones	Inspección			
Motor	Termostato	Inspección visual y prueba de funcionamiento	Inspección			Bimestral
	Sellos de bloqueo	Verificar estado	Inspección			
	Filtro de aceite	Limpieza de filtro	Limpieza			
Neumáticos	Ruedas	Raspado mecánico	Inspección			Mensual
Dirección	Barra de dirección	Inspección visual en busca de desgaste	Inspección			Semestral
	Caja de dirección	Inspección antifugas de líquido	Inspección			
	Mangueras	Verificación de ajuste y estado	Inspección			
	Juntas universales	Inspección de desgaste	Inspección			
Eléctrico	Batería	Verificación de estado de carga	Inspección			Anual
	Fusibles y relés	Inspección de fusibles quemados	Inspección			
	Motor de arranque	Inspección de conexiones eléctricas	Inspección			
	Alternador	Inspección de conexiones eléctricas	Inspección			

Figure 5. SNF maintenance schedule – 01

<u>Design of the Autonomous Maintenance</u>

Autonomous maintenance was implemented to empower drivers and reduce reliance on external maintenance teams, addressing inefficiencies related to low unit availability (58%). Training programs were conducted for all drivers, focusing on essential tasks such as tire inspections, oil level monitoring, and the interpretation of vehicle dashboard signals. These sessions resulted in a 20% reduction in minor maintenance delays. Furthermore, a set of standardized tools was distributed across the fleet to facilitate routine inspections and minor repairs. Drivers were required to conduct daily inspections before starting operations, with compliance rates reaching 95% within three months of implementation. This approach not only enhanced equipment reliability but also fostered a culture of accountability among personnel, significantly reducing downtime due to preventable issues.

Figure 6 presents the cleaning and inspection log format designed for autonomous maintenance activities on the SNF-01 truck. The cleaning section includes tasks such as exterior body cleaning to remove dust and dirt, headlight and taillight cleaning to prevent obstructions, and cleaning of mirrors, ensuring they remain free of stains and dust. Additional tasks involve cabin cleaning, removal of trash, and cleaning hand tools to maintain them grease-free. Filters and radiators are inspected and cleaned to ensure proper airflow and prevent residue buildup.

The inspection section focuses on safety and functionality, verifying the operation of lights and signals, visually checking brake pads and discs for wear, and ensuring tires are properly inflated and free of excessive wear. The log allows operators to document whether tasks were completed and to note any observations, facilitating systematic tracking of vehicle maintenance and ensuring optimal operational readiness.

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REGISTRO DE LIMPIEZA E INSPECCIONES AUTÓNOMAS

N° de Camión:__________ Mes:_______

Responsable:__________

Fecha:__________

LIMPIEZA

Limpieza	Objetivo	Sí	No	Observaciones
Limpieza de carrocería	Remover polvo y suciedad de la superficie exterior.			
Limpieza de faros y luces traseras	Asegurarse de que no haya obstrucciones de suciedad.			
Limpieza de espejos retrovisores	Mantenerlos libres de polvo y manchas.			
Limpieza de cabina del conductor	Incluye barrer y eliminar basura.			
Limpieza de herramientas de mano	Asegurarse de que estén libres de grasa y suciedad.			
Limpieza del filtro de aire	Verificar y limpiar según sea necesario.			
Limpieza de radiador	Remover insectos, hojas y otros residuos.			
Limpieza de sistema de escape	Inspeccionar visualmente y limpiar si es necesario.			

INSPECCIÓN

Seguridad y Funcionamiento	Objetivo	Sí	No	Observaciones
Verificación de luces y señales	Asegurarse de que todas las luces y señales funcionen correctamente.			
Revisión de frenos	Chequear visualmente el estado de las pastillas y discos de freno.			
Verificación de neumáticos	Revisar presión y desgaste de las llantas.			

Figure 6. Cleaning and inspection format

Figure 7 displays the daily unit cleaning and care record for the SNF-01 truck, managed under the supervision of Luis Alberto Rodríguez Campos. The log includes entries for February, detailing the driver's name, date of cleaning, observations, and the driver's signature to confirm task completion. For instance, on February 2, an observation was recorded to replace the cleaning cloth, while the remaining days show no additional notes. Drivers Sergio Fernández and Emilio Moreno alternated duties during the month, ensuring consistent adherence to the maintenance schedule. This record provides a systematic way to monitor cleaning routines, track compliance, and document any issues requiring attention, contributing to the vehicle's upkeep and operational reliability.

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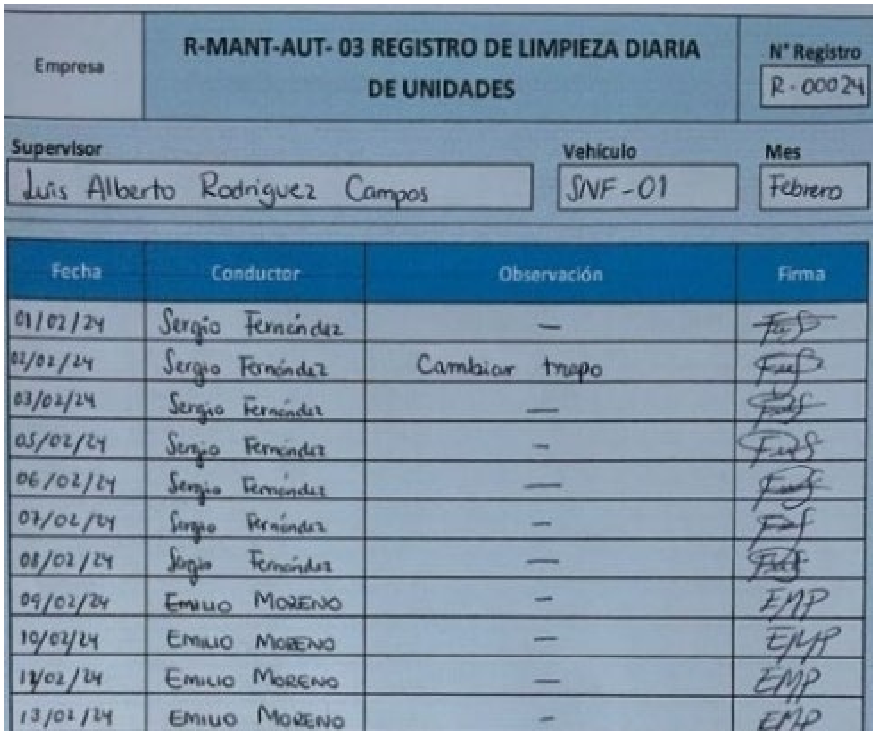

Empresa	R-MANT-AUT- 03 REGISTRO DE LIMPIEZA DIARIA DE UNIDADES	N° Registro R-00024

Supervisor: Luis Alberto Rodriguez Campos — Vehiculo: SNF-01 — Mes: Febrero

Fecha	Conductor	Observación	Firma
01/02/24	Sergio Fernández	—	[illegible]
02/02/24	Sergio Fernández	Cambiar trapo	[illegible]
03/02/24	Sergio Fernández	—	[illegible]
05/02/24	Sergio Fernández	—	[illegible]
06/02/24	Sergio Fernández	—	[illegible]
07/02/24	Sergio Fernández	—	[illegible]
08/02/24	Sergio Fernández	—	[illegible]
09/02/24	Emilio Moreno	—	EMP
10/02/24	Emilio Moreno	—	EMP
11/02/24	Emilio Moreno	—	EMP
13/02/24	Emilio Moreno	—	EMP

Figure 7. Unit cleaning and care record

Figure 8 displays the autonomous maintenance inspection schedule for the SNF-01 truck, outlining tasks categorized by unit components. The schedule includes regular inspections for tires, oils, liquids, shock absorbers, and steering. Tire maintenance involves visual checks, air pressure measurement, and valve condition reviews. Oils and liquids are inspected for levels and conditions, including windshield washer fluid, ensuring all systems operate efficiently. Shock absorbers undergo oil leak inspections, visual checks for spring conditions, and assessments of suspension bars and links. The steering system is reviewed for proper alignment to ensure safe handling. These inspections are conducted biweekly by the drivers, who are responsible for completing all tasks. This structured schedule promotes consistent monitoring of vehicle components, reducing the risk of unexpected failures and supporting proactive maintenance practices for operational reliability.

Cronograma de mantenimiento autónomo					
Pieza de la unidad	**Acción**	**Tipo**	**Responsable**	**Semana Inicial**	**Periodicidad**
Neumáticos	Revisión visual	Inspección	Conductor	1	Quincenal
	Medición de presión de aire				
	Revisión visual de válvulas				
Aceites y líquidos	Revisión de nivel de aceite				
	Revisión de condición de aceite				
	Revisión del nivel del líquido de parabrisas				
	Revisión de condición de líquido de parabrisas				
Amortiguadores	Revisión antifugas de aceite				
	Revisión visual de muelles				
	Revisión visual de barras y enlaces de suspensión				
Dirección	Revisión visual de alineación de volante				

Figure 8. Maintenance inspections schedule of SNF-01

4.4 Process Management Implementation

Process management techniques were employed to streamline the company's distribution processes, particularly in fuel supply and cargo securing operations. An AVA-ECRS matrix analysis identified redundant activities and bottlenecks, leading to the redesign of workflows. For example, the average refueling time was reduced from 20 minutes to 12 minutes, representing a 40% improvement. Standard operating procedures (SOPs) were developed and communicated to all staff, ensuring consistency and adherence to the redesigned processes. Process mapping also revealed inefficiencies in cargo securing, which previously accounted for 22% of delivery delays due to improper loading. Following the redesign, securement times decreased by 18%, contributing to improved delivery reliability. The integration of these improvements into daily operations was monitored through newly established performance reviews, which showed a 7% increase in On-Time In Full (OTIF) delivery rates within the first quarter of implementation.

Figure 9 illustrates the fuel control flowchart, detailing the steps involved in managing fuel usage for the SNF-01 truck. The process begins with the operations coordinator recording the vehicle's mileage. The driver then inspects key components using the P-MANT.AUT01 checklist before proceeding to the fuel station. Observations are logged in the R-MANT.AUT01 form, ensuring any identified issues are documented.

At the fuel station, the driver requests an electronic invoice for the fuel purchase. Once refueling is completed, safety measures are applied, including securely closing the tank valve. The invoice is subsequently recorded and archived for calculating fuel efficiency. Upon returning to the garage, the vehicle's final mileage is logged, completing the process. This systematic approach ensures proper fuel usage monitoring, enhances operational accountability, and supports data-driven decision-making to optimize vehicle performance and resource management.

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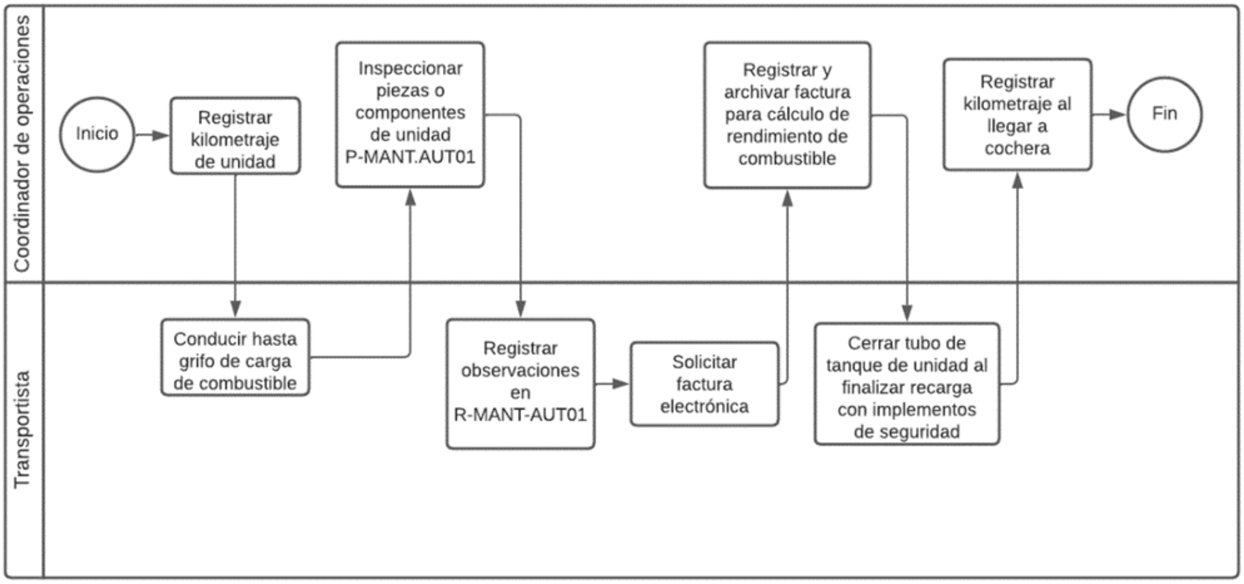


Figure 9. Fuel control flowchart

Figure 10 illustrates the flowchart for load securing, detailing the roles and responsibilities across different departments to ensure safe and efficient cargo handling. The process begins with the sales assistant sending the safety registration form (R-OPE-01) to the client, who then returns the completed form. The operations coordinator defines safety measures and prepares specifications for the transport. If additional resources are needed, a request is submitted to the purchasing assistant, who generates and sends a cost estimate for approval by the manager.

Once approved, the instructions for transport are provided to the driver. A check is conducted to ensure the driver is adequately trained; if not, training is scheduled before proceeding. The process concludes with the driver confirming their readiness for the task. This structured workflow ensures that all safety and operational requirements are met, minimizing risks and enhancing coordination across the organization.

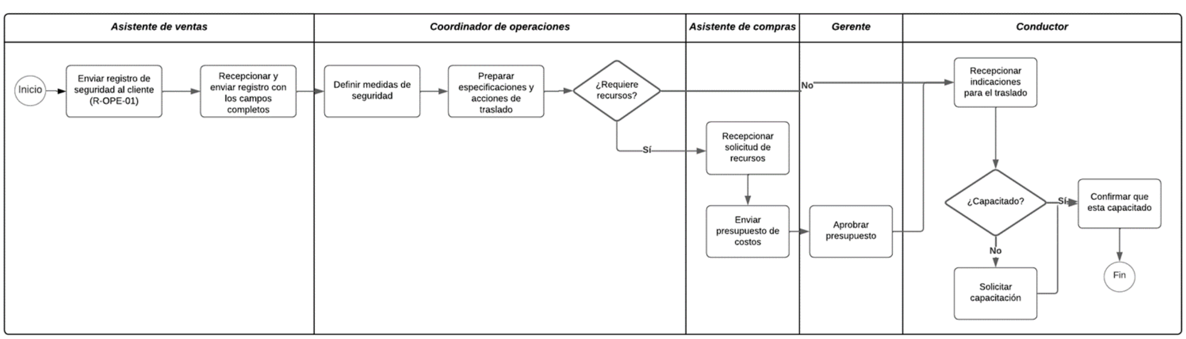
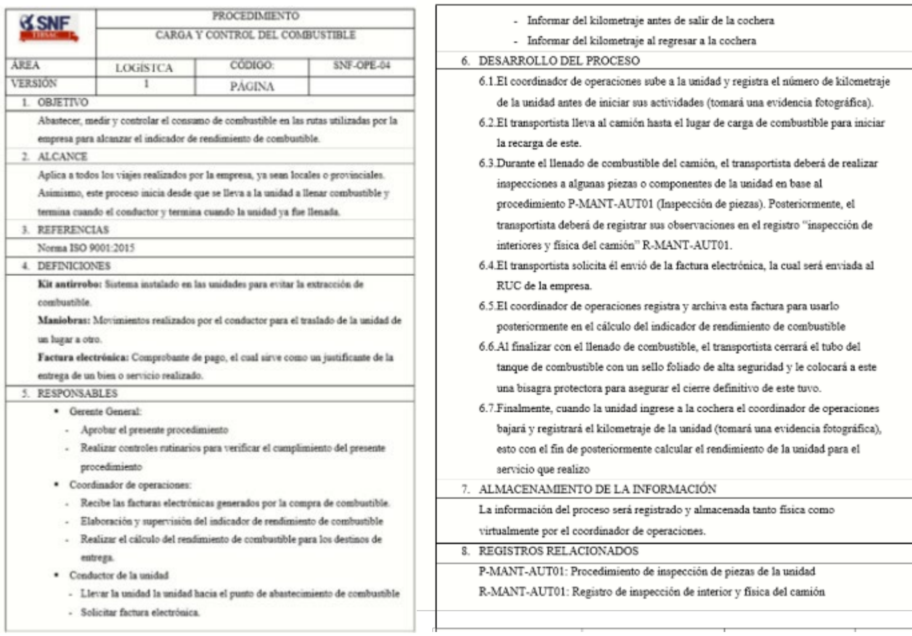


Figure 10. Flow chart for load securing

Figure 11 outlines the fuel loading and control procedure implemented to manage fuel usage for vehicles in the case study. The document specifies the objective, scope, definitions, responsibilities, and process steps to ensure accurate measurement and monitoring of fuel consumption.The procedure begins with the operations coordinator logging the vehicle’s mileage before any activity. The driver transports the vehicle to the fuel station, performs inspections of critical components according to the P-MANT.AUT01 checklist, and records observations in the R-MANT.AUT01 register. Once refueling is complete, the driver securely seals the fuel tank using high security seals and requests an electronic invoice, which is later archived for calculating fuel efficiency.

Upon returning to the garage, the driver logs the final mileage, supported by photographic evidence. This data is used to calculate the vehicle's performance metrics. The process ensures compliance with ISO 9001:2015 standards, promoting operational transparency and optimizing fuel usage through systematic tracking and documentation.



SNF	PROCEDIMIENTO CARGA Y CONTROL DEL COMBUSTIBLE		
ÁREA	LOGÍSTCA	CÓDIGO:	SNF-OPE-04
VERSIÓN	1	PÁGINA	

1. OBJETIVO

Abastecer, medir y controlar el consumo de combustible en las rutas utilizadas por la empresa para alcanzar el indicador de rendimiento de combustible.

2. ALCANCE

Aplica a todos los viajes realizados por la empresa, ya sean locales o provinciales. Asimismo, este proceso inicia desde que se lleva a la unidad a llenar combustible y termina cuando el conductor y termina cuando la unidad ya fue llenada.

3. REFERENCIAS

Norma ISO 9001:2015

4. DEFINICIONES

Kit antirrobo: Sistema instalado en las unidades para evitar la extracción de combustible.

Maniobras: Movimientos realizados por el conductor para el traslado de la unidad de un lugar a otro.

Factura electrónica: Comprobante de pago, el cual sirve como un justificante de la entrega de un bien o servicio realizado.

5. RESPONSABLES

- Gerente General:
  - Aprobar el presente procedimiento
  - Realizar controles rutinarios para verificar el cumplimiento del presente procedimiento
- Coordinador de operaciones:
  - Recibe las facturas electrónicas generados por la compra de combustible.
  - Elaboración y supervisión del indicador de rendimiento de combustible
  - Realizar el cálculo del rendimiento de combustible para los destinos de entrega.
- Conductor de la unidad
  - Llevar la unidad la unidad hacia el punto de abastecimiento de combustible
  - Solicitar factura electrónica.
  - Informar del kilometraje antes de salir de la cochera
  - Informar del kilometraje al regresar a la cochera

6. DESARROLLO DEL PROCESO

6.1. El coordinador de operaciones sube a la unidad y registra el número de kilometraje de la unidad antes de iniciar sus actividades (tomará una evidencia fotográfica).

6.2. El transportista lleva al camión hasta el lugar de carga de combustible para iniciar la recarga de este.

6.3. Durante el llenado de combustible del camión, el transportista deberá de realizar inspecciones a algunas piezas o componentes de la unidad en base al procedimiento P-MANT-AUT01 (Inspección de piezas). Posteriormente, el transportista deberá de registrar sus observaciones en el registro "inspección de interiores y física del camión" R-MANT-AUT01.

6.4. El transportista solicita él envió de la factura electrónica, la cual será enviada al RUC de la empresa.

6.5. El coordinador de operaciones registra y archiva esta factura para usarlo posteriormente en el cálculo del indicador de rendimiento de combustible

6.6. Al finalizar con el llenado de combustible, el transportista cerrará el tubo del tanque de combustible con un sello foliado de alta seguridad y le colocará a este una bisagra protectora para asegurar el cierre definitivo de este tuvo.

6.7. Finalmente, cuando la unidad ingrese a la cochera el coordinador de operaciones bajará y registrará el kilometraje de la unidad (tomará una evidencia fotográfica), esto con el fin de posteriormente calcular el rendimiento de la unidad para el servicio que realizo

7. ALMACENAMIENTO DE LA INFORMACIÓN

La información del proceso será registrado y almacenada tanto física como virtualmente por el coordinador de operaciones.

8. REGISTROS RELACIONADOS

P-MANT-AUT01: Procedimiento de inspección de piezas de la unidad

R-MANT-AUT01: Registro de inspección de interior y física del camión

Figure 11. Fuel loading and control procedure

5. Results

In Table 1, the results of validating the proposed maintenance management model, based on TPM tools and process management, are detailed. The OTIF indicator showed a 7.24% improvement, while availability and on-time delivery rates increased by 3.81% and 3.80%, respectively. Additionally, fuel shortages decreased significantly by 50%, and the damaged load index dropped by 23.20%. These results highlight the model's effectiveness in addressing key operational challenges, improving resource utilization, and enhancing reliability and service quality across the distribution process.

Table 1. Results of validation of the proposed model

Indicator	Unit	As is	To be	Results	Variation
OTIF (On Time In Full)	%	75.25%	90%	80.70%	7.24%
On-Time Delivery Rate	%	86.00%	93%	89.27%	3.80%
Availability	%	89.80%	96%	93.22%	3.81%
Fuel Shortage Percentage	%	8%	3%	4.00%	-50.00%
Damaged Load Index	%	12.50%	4.00%	9.60%	-23.20%

6. Conclusions.

The conclusions derived from the research encapsulate the findings, reflect on their significance, discuss contributions to the industrial engineering field, and offer observations and suggestions for future investigations.

The study systematically identified the pressing issues facing heavy goods transport SMEs in Peru, including low service levels and inefficiencies in distribution processes, with the OTIF rate being a critical area of concern. The implementation of a maintenance management model integrating Total Productive Maintenance (TPM) and Process Management addressed these inefficiencies effectively. Key findings showed a 7.24% improvement in the OTIF indicator, alongside a 50% reduction in fuel shortages and a 23.20% decrease in damaged load index. The planned and autonomous maintenance strategies contributed significantly to these outcomes, highlighting their potential to enhance operational performance. By focusing on systematic maintenance scheduling and empowering drivers through autonomous maintenance, the model demonstrated the feasibility of achieving cost-effective, sustainable improvements in equipment reliability and service delivery.

This research underscores the importance of integrating structured maintenance methodologies with operational strategies in SMEs. The study's emphasis on aligning maintenance activities with organizational objectives reflects its contribution to operational sustainability and service quality in the heavy goods transport sector. By addressing gaps in existing maintenance practices, the proposed model not only improved the operational metrics of the case study but also provided a replicable framework applicable to similar contexts. The results validate the strategic value of TPM and Process Management as complementary approaches for enhancing resource utilization and reliability.
The contributions to the field are manifold. First, the study bridges a significant research gap by extending TPM methodologies to SMEs in the transport sector, a domain often overlooked in the literature. Second, it offers a practical application of process management in maintenance, demonstrating its role in reducing inefficiencies and aligning operational goals. Third, the findings provide actionable insights for practitioners seeking to implement maintenance strategies in resource-constrained environments, thereby promoting broader adoption of these methodologies in similar industrial settings.

Observations indicate that while the proposed model achieved measurable improvements, the long-term success of such interventions depends on continuous training, adherence to maintenance schedules, and regular performance evaluations. Future studies could explore integrating digital tools, such as IoT-based monitoring systems, to further enhance the predictive maintenance capabilities and scalability of the model. Additionally, comparative analyses involving multiple SMEs across different industrial sectors could provide a broader understanding of the model's adaptability and limitations. Such investigations would enrich the academic discourse on maintenance management while offering practical solutions for industry stakeholders. The findings and framework presented herein establish a foundation for ongoing research and practical advancements in maintenance management for SMEs, fostering a culture of continuous improvement and operational excellence.

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