

MidOcean University

Faculty of Management

Department / Specialization: MBA



Enhancing Maintenance by applying Lean Methodology in Railway Vehicle

Prepared by the Student: Mazen Salem Ahmed Bawazir

Supervised by:

Dr. Al-Faisal Abdulhamid

Dr. Fayez Jarad

Academic Year:

2025

Introduction

Railway maintenance has relied on time-based, mileage-based, or condition-based strategies, often implemented in isolation or through loosely integrated frameworks. These methods generally involve routine inspections and scheduled interventions that are executed based on fixed intervals or accumulated kilometers. While these strategies provide a basic level of predictability, they are often inefficient, inflexible, and costly, especially when they fail to respond dynamically to the actual condition of components or the evolving needs of the operation. This can result in both under-maintenance (risking safety and failure) and over-maintenance (leading to wasted labor, spare parts, and lost operational time).

Adding to the challenge is the presence of siloed maintenance functions, fragmented communication between departments, and limited real-time visibility into the end-to-end maintenance process. These factors contribute to longer turnaround times, inefficient allocation of resources, and decreased availability of serviceable trains. In such contexts, the traditional approaches fail to offer a holistic understanding of the maintenance system as an interconnected workflow.

To address these persistent inefficiencies, there is an increasing need for railway organizations to adopt modern, integrated, and process-oriented methodologies. Among these, Lean thinking has emerged as a promising paradigm for achieving operational excellence. Initially developed by Toyota for manufacturing, Lean has been successfully applied in a wide range of industries including healthcare, aviation, logistics, and public services. Its core principle eliminating waste (Muda), creating flow, empowering employees, and delivering customer value are directly applicable to maintenance environments where time, quality, and reliability are critical.

Within the Lean toolkit, Value Stream Mapping (VSM) stands out as a particularly valuable technique. VSM is a structured visual approach for analyzing and improving processes by identifying all the steps involved, distinguishing between those that add value and those that do not, and redesigning the workflow to achieve a more efficient “future state.” When applied to railway vehicle maintenance, VSM can reveal hidden bottlenecks, redundant approvals, material delays, excessive handling, and rework loops that contribute to performance shortfalls.

By leveraging VSM, maintenance organizations can gain a comprehensive and data-driven understanding of their operations, enabling them to reduce waste, minimize downtime, optimize resource usage, and enhance cross-functional collaboration. Importantly, VSM supports the creation of a culture of continuous improvement, empowering frontline staff to participate in problem-solving and process innovation.

This research seeks to investigate the integration of Lean principles, especially Value Stream Mapping (VSM) into the railway vehicle maintenance process. The goal is to map the current state of maintenance operations, identify inefficiencies and non-value-adding steps, and propose a redesigned maintenance process aligned with Lean thinking. Through the development and analysis of a future state map, the study aims to demonstrate how Lean methodology can be applied to improve maintenance efficiency, increase fleet availability, and support the strategic transformation of railway services.

Ultimately, this research contributes to the broader objectives of enhancing the resilience, safety, and sustainability of transportation infrastructure by equipping maintenance operations with tools and strategies that are both practical and scalable.

Research Problem

Maintenance plays a critical role in sustaining the operational integrity, safety, and cost-efficiency of railway systems. Ensuring that railway vehicles are properly maintained is essential not only for the timely movement of passengers and cargo but also for preventing breakdowns, extending the lifespan of assets, and minimizing operational disruptions. However, despite the strategic importance of maintenance, many railway organizations continue to rely on conventional, schedule-driven maintenance practices, such as fixed time intervals, mileage thresholds, and manual inspections.

While these traditional methods offer a structured approach to maintenance planning, they are increasingly misaligned with the complexity, scale, and performance demands of modern railway systems. Such approaches tend to be reactive rather than preventive, and rigid rather than responsive. Maintenance may be performed too frequently, resulting in unnecessary labor and parts usage, or too late, increasing the risk of equipment failure, unplanned downtime, and compromised safety. These inefficiencies are further exacerbated by the heavy reliance on human judgment, which introduces variability, subjectivity, and inconsistency into maintenance processes.

In many cases, maintenance activities are carried out in functional silos with limited cross-departmental visibility. The absence of standardized data collection, real-time monitoring, and process flow visibility leads to poor coordination, fragmented communication, and duplication of effort. As a result, organizations often struggle to manage maintenance proactively, to identify the root causes of performance gaps, or to align maintenance activities with broader operational goals.

A core issue underlying these challenges is the lack of a systematic methodology to map, analyze, and optimize maintenance workflows. Without a visual and data-driven representation of how maintenance tasks are initiated, executed, and completed, it is difficult for organizations to differentiate between value-adding activities (those that directly contribute to vehicle readiness and safety) and non-value-adding activities (such as waiting time, rework, unnecessary approvals, or excess movement of personnel and materials).

Value Stream Mapping (VSM), a foundational tool within Lean methodology, provides a structured and visual approach to addressing this gap. VSM allows maintenance teams to capture a detailed view of the current process, highlighting inefficiencies and making hidden forms of waste visible. Through the creation of a “future state map”, organizations can redesign workflows to eliminate waste, reduce delays, enhance resource coordination, and improve overall process flow.

Although VSM has demonstrated effectiveness in manufacturing, healthcare, aviation, and logistics sectors, it remains underutilized in the context of railway maintenance,

particularly for system-wide, strategic applications. Most railway organizations have yet to explore how Lean tools like VSM can serve as catalysts for proactive, value-focused maintenance transformation. This represents a significant research and practice gap.

Therefore, the problem this study addresses is the continued reliance on outdated, fragmented, and inefficient maintenance practices in railway vehicle operations, and the absence of an integrated, lean-based analytical framework such as Value Stream Mapping to guide performance improvement. This research seeks to demonstrate the utility of VSM as a process improvement tool for railway maintenance, showing how it can be used to identify inefficiencies, visualize end-to-end workflows, and design a more effective, agile, and reliable maintenance model.

Significance of Study

This research is of considerable significance as it introduces Lean thinking and Value Stream Mapping (VSM) into the underexplored domain of railway vehicle maintenance, where operational inefficiencies can lead to widespread disruptions, safety risks, and financial strain. The study's relevance spans operational enhancement, strategic advancement, academic contribution, and societal impact, making it timely and vital in the context of modern transportation challenges.

From an operational standpoint, railway maintenance departments often grapple with complex workflows, fragmented communication, and outdated scheduling systems. VSM offers a structured approach to visually map out maintenance processes, helping teams uncover bottlenecks, unnecessary handoffs, and redundancies such as idle time, motion waste, or excess inventory. By applying VSM, organizations can streamline operations, reduce turnaround time, and improve asset utilization, resulting in better availability of rolling stock and more efficient use of maintenance resources.

Strategically, the adoption of Lean principles represents a paradigm shift from reactive, schedule-driven maintenance to a more proactive, data-informed model. This transition supports the development of preventive strategies that extend equipment life, lower the frequency of unplanned repairs, and reduce operational costs. Furthermore, it aligns with broader performance goals such as reliability-centered maintenance and just-in-time operations, creating a leaner, more agile railway system capable of adapting to dynamic service demands.

Academically, this research fills an important gap in literature. While Lean tools like VSM are well-documented in manufacturing, aviation, and healthcare, there is limited empirical evidence of their application in railway vehicle maintenance—particularly at the operational level. By addressing this gap, the study contributes to a growing interdisciplinary discourse that integrates industrial engineering, transport logistics, and infrastructure management, offering a foundation for future research in transportation sector innovation.

In conclusion, this study is significant not only because it addresses tangible maintenance inefficiencies, but also because it promotes a culture of continuous improvement and innovation within the railway sector. It aims to serve as a catalyst for lean transformation in public transportation systems, ultimately fostering safer, smarter, and more sustainable infrastructure services.

Objectives of the Study

The overarching aim of this study is to explore the practical application of Lean methodology, with a specific focus on Value Stream Mapping (VSM), as a means to enhance the efficiency, effectiveness, and reliability of railway vehicle maintenance operations. The study is designed to address both theoretical and practical gaps in maintenance optimization within the transportation sector. The following specific objectives will guide the research process:

1. To systematically analyze current railway vehicle maintenance practices by mapping existing workflows using VSM techniques. This objective involves capturing and visualizing all operational steps involved in the maintenance process—from initial diagnostics to task execution and vehicle readiness—providing a detailed picture of how value flows (or is lost) throughout the system.
2. To identify inefficiencies, delays, and non-value-adding activities embedded within current maintenance operations. These may include excessive wait times, underutilized manpower, overprocessing, unnecessary transportation of parts or vehicles, rework due to poor communication, and redundant approvals. The goal is to create a baseline understanding of the root causes of performance loss and waste.
3. To design an improved “future state” maintenance process based on Lean principles, emphasizing streamlined operations, optimized task sequencing, enhanced communication, and reduced downtime. This redesigned process will incorporate standardized work procedures, visual controls, better planning and scheduling, and alignment of resources to actual maintenance needs.
4. To assess the impact of the proposed lean-based model through quantitative and qualitative measures, including key performance indicators (KPIs) such as:
 - Mean Time to Repair (MTTR)
 - Mean Time Between Failures (MTBF)
 - Overall Equipment Effectiveness (OEE)
 - Maintenance cycle time
 - Downtime frequency and duration
 - Vehicle availability and reliabilityThese metrics will provide a concrete basis for evaluating the effectiveness of lean intervention.

5. To explore the readiness, capabilities, and barriers to lean implementation among maintenance personnel and organizational leadership. This includes identifying potential resistance to change, training needs, and resource constraints that could affect the adoption of Lean practices in a railway context.
6. To develop practical recommendations and a scalable framework that can be adopted by other maintenance facilities within the railway industry or in similar asset-intensive sectors. The goal is to ensure the sustainability of lean transformations and support ongoing process improvement efforts through repeatable and adaptable methodologies.

By fulfilling these objectives, the study aims to provide actionable insights into how Lean thinking can be integrated into traditional maintenance systems, ultimately leading to better performance, safer operations, and more cost-effective use of public infrastructure.

Research Questions

This study seeks to investigate how Lean methodology, and specifically Value Stream Mapping (VSM), can be leveraged to improve the efficiency, effectiveness, and responsiveness of railway vehicle maintenance operations. The research questions are crafted to guide a systematic inquiry into existing maintenance inefficiencies, the diagnostic and transformative power of VSM, and the measurable outcomes of adopting Lean principles in this context.

1. What are the current inefficiencies, redundancies, and sources of waste embedded in railway vehicle maintenance workflows, and how do these issues affect key operational metrics such as maintenance lead time, fleet availability, service punctuality, and cost control?
 - This question aims to establish a baseline diagnosis of the existing system, focusing on how conventional maintenance practices contribute to resource misalignment, prolonged downtime, or quality issues. It also seeks to understand the impact of these inefficiencies on overall operational reliability.
2. How can Value Stream Mapping (VSM) be applied as a visual and analytical tool to map, assess, and diagnose maintenance processes, and what types of non-value-adding activities (e.g., waiting, rework, excess motion, overprocessing) can be uncovered through this approach?
 - This question explores the methodological utility of VSM in a railway context. It investigates how VSM can provide transparency across departments, enable a shared understanding of workflow gaps, and facilitate the identification of inefficiencies that might otherwise remain hidden or unquantified.
3. What process enhancements and operational improvements can be realized by redesigning the current maintenance system into a Lean-based model, guided by the development and implementation of a future state map?
 - This question addresses the prescriptive potential of Lean thinking. It examines the types of workflow restructuring, standardization, and coordination that can emerge from the Lean redesign process, and how these changes can contribute to faster turnaround, higher predictability, and improved quality of service.
4. What tangible, quantifiable benefits can be achieved through the application of Lean methodology in railway vehicle maintenance, specifically in terms of:

- Reduced Mean Time to Repair (MTTR)
 - Lower maintenance costs
 - Increased equipment availability and service readiness
 - Improved staff productivity and task efficiency?
 - This question aims to evaluate the impact of Lean implementation through performance metrics and key performance indicators (KPIs). It seeks to link Lean theory to practice by measuring its effectiveness in improving technical, economic, and service-related outcomes.
5. How can the insights from this study inform a scalable and sustainable framework for Lean maintenance transformation across other departments, facilities, or transportation systems with similar operational challenges?
- This additional, forward-looking question considers the broader applicability of the findings. It aims to evaluate how the lessons learned from this case study can be generalized, replicated, or adapted by other maintenance units within or beyond the railway sector.

Together, these research questions offer a comprehensive roadmap for understanding the current state of railway maintenance, testing the applicability of Lean tools, and designing a practical strategy for performance improvement rooted in evidence-based decision-making and operational transparency.

Research Hypotheses

To empirically examine the impact of applying Lean methodology—with a focus on Value Stream Mapping (VSM) in railway vehicle maintenance environments, the following hypotheses have been developed. These hypotheses reflect assumptions derived from both existing Lean theory and practical observations in comparable sectors (e.g., manufacturing, healthcare, aviation), and they guide the analytical framework of this study.

- H1: The application of Value Stream Mapping (VSM) will lead to a statistically significant reduction in non-value-adding activities (NVA) within railway vehicle maintenance workflows.

This hypothesis tests the foundational claim that VSM, as a diagnostic tool, can uncover hidden inefficiencies within maintenance operations—such as excessive waiting times, redundant approval steps, unnecessary transport of parts, rework loops, and motion waste. The study will analyze before-and-after process maps to quantify the reduction in NVAs and assess improvements in process clarity, task flow, and inter-departmental coordination. A successful reduction in NVA indicates that Lean tools can generate targeted operational insights in asset-intensive environments like railway maintenance.

- H2: The implementation of Lean methodology will result in measurable improvements in the availability and serviceability of railway vehicles by enhancing maintenance scheduling, resource deployment, and task standardization.

This hypothesis focuses on evaluating the operational impact of Lean interventions. It posits that by improving process flow and removing bottlenecks, Lean practices can increase the proportion of trains available for daily operations, reduce unscheduled downtime, and enhance service readiness. These improvements will be measured through key performance indicators (KPIs) such as:

- Fleet availability rate
- Mean Time to Repair (MTTR)
- Turnaround time for scheduled maintenance
- On-time service performance related to maintenance outcomes

Improvements in these metrics will suggest that Lean methodology enables not only technical efficiencies but also strategic gains in operational reliability.

- H3: The adoption of Lean maintenance practices, when compared with traditional time-based maintenance approaches, will generate cost savings by reducing labor inefficiencies, minimizing premature part replacements, and extending equipment life cycles.

This hypothesis addresses the financial dimension of Lean implementation. Traditional maintenance often incurs unnecessary costs due to over-maintenance, duplication of work, or untimely intervention. Lean practices aim to replace these rigid schedules with more dynamic, value-aligned processes. This study will assess cost implications through comparative analysis of:

- Labor hours spent per maintenance task
- Material and spare parts consumption
- Maintenance cost per unit of service output
- Long-term asset performance trends

Demonstrating cost efficiency will further strengthen the case for Lean adoption in capital-intensive, public service-driven sectors like rail transport.

Together, these hypotheses aim to validate the holistic value proposition of Lean methodology in railway maintenance—spanning operational efficiency, strategic availability, and economic viability. If confirmed, the findings will provide a strong empirical basis for integrating VSM and Lean tools into railway maintenance policy, planning, and execution at scale.

Previous Studies

Over the past two decades, a substantial body of research has emerged highlighting the impact of Lean maintenance practices on improving operational efficiency, reducing costs, and enhancing service reliability across various industries. These practices have been especially prominent in asset-intensive environments, where downtime, inefficiency, or maintenance errors can lead to significant operational and financial consequences.

In the manufacturing sector, Lean tools such as 5S, Kaizen, Just-in-Time (JIT), and Value Stream Mapping (VSM) have become foundational strategies for optimizing production systems and maintenance operations. These tools are used to standardize tasks, eliminate waste (Muda), and improve workflow visibility. For example, Sharma et al. (2019) demonstrated that the application of Lean tools in a mid-sized manufacturing plant led to a 25% reduction in equipment downtime, showcasing the adaptability and effectiveness of Lean principles in structured industrial environments. Their findings emphasized the importance of continuous improvement cycles and visual process management as enablers of sustainable performance gains.

The aviation and healthcare sectors have also been early adopters of Lean maintenance and operations practices, given their need for high reliability, strict compliance standards, and minimal tolerance for failure. In aviation, Lean has been used to enhance aircraft maintenance operations by improving hangar flow, reducing turnaround times, and ensuring safety-critical procedures are executed efficiently. Similarly, in healthcare, Lean tools like VSM have been instrumental in optimizing patient flow, reducing waiting times, and ensuring effective resource utilization. These industries share parallels with the railway sector—most notably in terms of safety sensitivity, regulatory oversight, and dependence on well-maintained equipment—making the lessons learned highly relevant and transferrable.

Within the railway industry, however, Lean methodology—particularly Value Stream Mapping—remains underutilized and under-researched. Most existing studies in the railway maintenance domain focus on Total Productive Maintenance (TPM) and Condition-Based Monitoring (CBM). TPM emphasizes maximizing equipment effectiveness through preventive maintenance and employee ownership, while CBM uses sensor data and diagnostics to predict failures and optimize maintenance timing. Although these approaches provide valuable contributions, they are often implemented as technology-driven or culture-driven strategies without a cohesive process-mapping framework that ties together frontline operations with system-wide process flow.

What is noticeably absent in much of the current railway literature is a process-centric approach that enables stakeholders to visualize how maintenance activities are performed end-to-end—from scheduling and resource allocation to execution and post-maintenance validation. Very few empirical studies have applied VSM in railway vehicle maintenance to examine process delays, value loss, or resource waste from a workflow perspective. This highlights a critical gap in both academic inquiry and industry application.

The limited examples that do exist often frame VSM at a conceptual level, with minimal attention to how it is practically implemented within day-to-day maintenance operations. Moreover, existing literature tends to focus on digital monitoring systems, asset lifecycle models, or policy

recommendations, with less emphasis on operational design, cross-functional coordination, and shop-floor process visibility.

This study aims to address these limitations by introducing Value Stream Mapping as a practical diagnostic and improvement tool for railway vehicle maintenance workflows. It builds upon Lean theory but translates it into a maintenance context that is often constrained by legacy systems, siloed operations, and fixed scheduling models. By doing so, it contributes to bridging the gap between Lean principles and real-world maintenance execution, offering railway operators a structured, visual, and participatory approach to continuous improvement.

Theoretical Framework

This study is grounded in the principles of Lean Manufacturing, a systematic methodology originally developed by Toyota to eliminate waste, improve quality, and increase value delivery in production systems. Over the past few decades, Lean thinking has evolved into a comprehensive operational and managerial philosophy, widely adopted not only in manufacturing but also in service sectors, public administration, healthcare, aviation, and transportation—all areas where efficiency, reliability, and customer satisfaction are critical.

At its core, Lean is based on three foundational concepts:

- Muda – the identification and elimination of all forms of waste.
- Kaizen – the commitment to continuous, incremental improvement; and
- Customer value – the pursuit of processes that deliver value as defined by the end-user or stakeholder.

In the context of this study, Lean is applied not as a general concept but through the focused lens of Value Stream Mapping (VSM) a powerful diagnostic and improvement tool within the Lean toolkit. VSM allows organizations to create a detailed, visual map of how materials, tasks, and information flow through a process from start to finish. It exposes inefficiencies, redundancies, and non-value-adding steps, enabling decision-makers to design a "future state" that is more efficient, coordinated, and value-aligned.

In railway vehicle maintenance, where multiple systems interact (mechanical, electrical, administrative, and logistical), VSM offers a unique opportunity to integrate fragmented processes, eliminate waste, and ensure that each maintenance activity contributes directly to service readiness. The use of VSM provides visibility across the entire maintenance value chain—from work order initiation and resource allocation to inspection, repair, and release—revealing delays, bottlenecks, excessive handoffs, or duplicated tasks that often go unnoticed.

This theoretical framework incorporates and bridges several key dimensions:

1. Lean Operations and Process Optimization

Lean theory advocates for eliminating all forms of waste (e.g., overproduction, waiting, unnecessary transport, defects, underutilized talent) while maximizing flow, standardization, and customer value. In maintenance, this translates to reducing maintenance turnaround times, increasing asset availability, and improving task reliability.

2. Value Stream Mapping as a Lean Tool

VSM is both a conceptual and practical framework. It provides visual language for teams to map current-state processes, identify inefficiencies, and co-design an improved future state. In this study, VSM serves as a methodology for mapping and redesigning the railway maintenance process to be more streamlined, transparent, and outcome oriented.

3. Systems Thinking

Railway maintenance is not isolated; it involves coordination among departments (planning, procurement, quality assurance, operations). System thinking enables the understanding of how feedback loops, interdependencies, and process delays propagate through the network. It ensures that interventions at one point in the system do not create unintended inefficiencies elsewhere.

4. Preventive and Predictive Maintenance Theory

This dimension links Lean methodology with modern asset management principles. Instead of maintaining trains based on rigid time intervals, Lean-informed approaches seek to align maintenance actions with actual equipment conditions, usage patterns, and historical data. This hybrid approach supports both preventive reliability and resource efficiency.

5. Continuous Improvement Culture (Kaizen)

Beyond tools and frameworks, Lean encourages a mindset where every employee is engaged in identifying improvement opportunities. Applying this to railway maintenance empowers technicians, supervisors, and engineers to participate in ongoing process evaluation and contribute to innovation from the ground up.

By anchoring the research in this multi-layered theoretical framework, the study provides a structured foundation for analyzing current railway maintenance challenges and designing process improvements that are both practical and scalable. It also contributes to academic literature by operationalizing Lean theory in a complex, safety-critical, and under-researched domain.

Research Methodology

This study adopts a qualitative and analytical research design that integrates both exploratory and evaluative approaches to examine the potential of Lean methodology, with a particular focus on Value Stream Mapping (VSM), in enhancing the efficiency of railway vehicle maintenance processes. The methodology is structured to capture operational realities, assess systemic inefficiencies, and develop a data-informed improvement model rooted in Lean principles.

The research will be conducted through the following five interrelated phases:

1. Data Collection

The initial phase of the study involves the collection of primary qualitative data through a combination of:

- On-site observations: These will be conducted across various maintenance activities to record task execution sequences, downtime between stages, technician-tool interaction, and procedural adherence.
- Semi-structured interviews: Interviews will be held with key personnel including maintenance supervisors, technicians, operations managers, and planners. The aim is to gather insights into existing operational challenges, workflow structures, and perceptions of inefficiency or duplication.
- Review of operational documentation: Maintenance checklists, work orders, standard operating procedures (SOPs), shift logs, and internal audit reports will be examined to supplement and validate observations and interview data.

The use of data triangulation—drawing insights from multiple sources—will enhance the validity and reliability of the qualitative findings.

2. Process Mapping Using VSM

Based on the insights gathered, a current state Value Stream Map (VSM) will be constructed to visualize the end-to-end railway vehicle maintenance process. This visual representation will capture:

- Key operational steps and sub-processes
- Decision points and workflow dependencies

- Wait time, material flow, and information transfer
- Bottlenecks, rework loops, and idle labor or equipment

The map will serve as a diagnostic tool to identify non-value-adding activities, inefficiencies, and structural constraints. It will also provide a baseline for comparative analysis in subsequent phases.

3. Quantitative Assessment

To support the qualitative analysis, quantitative data will be extracted from maintenance records and time-motion studies. The following performance indicators will be analyzed:

- Mean Time to Repair (MTTR) – the average time taken to complete a repair
- Mean Time Between Failures (MTBF) – the average operational time between breakdowns
- Overall Equipment Effectiveness (OEE) – a comprehensive metric combining availability, performance, and quality

These metrics will be used to establish baseline performance and later measure the outcomes of Lean-based interventions. In addition, process-specific cycle times, resource utilization rates, and failure frequencies will be recorded for detailed analysis.

4. Design of Future State Map

In collaboration with maintenance staff and operational stakeholders, a future state VSM will be developed. This Lean-informed redesign will incorporate:

- Elimination or consolidation of non-value-adding steps
- Improved task sequencing and communication flow
- Reduced delays in approvals, material delivery, or inspection
- Integration of visual controls and performance monitoring checkpoints

The future state model will propose a more agile, efficient, and resource-aligned maintenance workflow aimed at minimizing downtime and maximizing vehicle availability.

5. Evaluation of Effectiveness

The final phase involves the comparative evaluation of pre- and post-intervention performance. The impact of the Lean-based improvements will be assessed using both:

- Quantitative comparisons (e.g., changes in MTTR, OEE, downtime frequency)
- Qualitative feedback (e.g., from technicians and supervisors on process clarity, workload balance, or morale)

Where possible, a cost-benefit analysis will be performed to estimate resource savings, labor efficiency improvements, and return on process change investments. This evaluative approach will validate the feasibility, scalability, and effectiveness of Lean applications in the railway maintenance environment.

By combining field-based qualitative insight with structured process analysis and quantitative performance evaluation, this methodology aims to generate actionable recommendations for practice and theoretical contributions to Lean implementation research, particularly within high-complexity service operations such as railway systems.

Study Tools

To conduct this research effectively and fulfill its objectives, a range of qualitative, quantitative, and process analysis tools will be employed. These tools are carefully selected to support comprehensive data collection, workflow visualization, and performance evaluation of maintenance practices in the railway sector. Their combined use will facilitate a rigorous and triangulated approach to diagnosing inefficiencies and designing lean-driven improvements.

1. Value Stream Mapping (VSM) Templates and Software

Specialized VSM templates and digital mapping software (e.g., Lucidchart, Microsoft Visio, or Lean-specific platforms) will be used to construct both the current state map and the future state map of the railway vehicle maintenance process. These tools provide a standardized visual framework to document process steps, information flows, wait times, and decision points. The resulting maps will serve as diagnostic instruments for identifying non-value-adding activities (NVA), process bottlenecks, and unnecessary complexities in the workflow.

2. Interview Guides for Maintenance Personnel

Custom-designed semi-structured interview guides will be used to ensure methodological consistency across stakeholder interviews while allowing for open-ended, context-specific responses. These guides will explore themes such as:

- Current operational challenges
- Perceived inefficiencies or delays
- Experiences with maintenance scheduling and execution
- Suggestions for process improvement

The interviews will be conducted with key actors across different roles—including technicians, team leads, quality inspectors, planners, and supervisors—to capture a diverse range of perspectives.

3. Observation Checklists

During on-site visits, structured observation checklists will be used to

systematically record observable maintenance tasks, time durations, equipment usage, task sequencing, and worker movement. These checklists will be aligned with standard operating procedures (SOPs) and Lean waste categories (e.g., waiting, motion, overprocessing) to ensure objectivity and comprehensiveness. This data will support real-time understanding of process execution and validate insights gained through interviews and documentation.

4. Maintenance Logs and Historical Data

Analysis of archival maintenance records—such as work orders, failure logs, repair history, inspection reports, and inventory movement—will provide historical insight into:

- Frequency of recurring faults
- Typical repair durations
- Unscheduled vs. scheduled interventions
- Equipment usage trends

These data points will form the quantitative foundation for evaluating the baseline condition of the maintenance system and establishing performance benchmarks for post-intervention analysis.

5. Performance Metrics and Key Performance Indicators (KPIs)

A set of operational metrics will be monitored to quantitatively assess the effectiveness of Lean methodology implementation. These include:

- Mean Time to Repair (MTTR) – average time required to complete maintenance tasks
- Overall Equipment Effectiveness (OEE) – a composite measure of availability, performance, and quality
- Mean Time Between Failures (MTBF) – average operational time between equipment failures
- Scheduled vs. Unscheduled Maintenance Frequency
- Maintenance backlog duration and closure rate

These indicators will be tracked before and after the introduction of Lean

practices to determine measurable improvements in efficiency, reliability, and cost-effectiveness.

Collectively, these tools will enable a multi-dimensional analysis of the current railway maintenance process and provide a robust foundation for the design, implementation, and evaluation of a Lean-based maintenance improvement model. They also ensure methodological transparency and academic rigor, reinforcing the credibility and practical relevance of the study findings.

Scope and Limitations of the Study

Scope:

This research will be conducted within the operational context of a single railway vehicle maintenance facility that forms part of a broader, defined transportation network. The study specifically targets periodic and scheduled maintenance activities, which include routine inspections, preventive procedures, and standardized service designed to maintain the functionality, safety, and availability of rolling stock. These processes are central to maintaining operational continuity, minimizing unscheduled downtime, and meeting regulatory and performance benchmarks.

The scope is deliberately focused on proactive maintenance activities, as opposed to reactive or corrective interventions. This focus aligns with the objectives of Lean methodology, which emphasizes planning, waste reduction, and process standardization rather than emergency response or fault recovery.

The study will employ direct field observations, semi-structured staff interviews, and review of historical maintenance data to develop a comprehensive understanding of how maintenance is currently executed. Central to this analysis is the use of Value Stream Mapping (VSM) as the primary Lean tool, which will be applied to:

- Map the current workflow
- Identify non-value-adding steps
- Redesign a more efficient “future state” process

This bounded scope allows for in-depth investigation of Lean’s applicability in a specific operational environment, while offering valuable insights into future studies or wider-scale implementation.

Limitations:

While the research is designed to yield actionable findings and practical recommendations, it is subject to several methodological and contextual limitations that must be acknowledged:

- **Context-Specific Findings**
The study is confined to a single facility within a specific organizational and regulatory setting. As a result, the findings may not be directly generalizable to other railway systems that differ in scale, maintenance strategy, cultural norms, or

governance frameworks. However, the methodological approach and analytical tools may still offer transferable value to similar operational environments.

- **Exclusion of Emergency and Corrective Maintenance**
The study intentionally excludes unplanned or corrective maintenance activities, such as breakdown response or failure-driven repairs. These processes often follow different workflows, involve real-time decision-making, and depend on dynamic resource allocation, which are not the primary focus of Lean-based optimization in this study. As such, the research does not address the full spectrum of maintenance operations.
- **Staff Engagement and Change Resistance**
One potential constraint is the resistance to change among maintenance personnel, particularly if Lean concepts are perceived as disruptive or misaligned with established practices. This could influence the openness of participants during interviews, or the accuracy of behavior observed during fieldwork. Steps will be taken to mitigate this risk through transparent communication, staff involvement, and respectful engagement.
- **Data Availability and Accuracy**
The effectiveness of VSM and subsequent performance evaluations depends on access to reliable historical maintenance data. Incomplete, outdated, or inconsistent records may limit the granularity of analysis or reduce the validity of quantitative findings. Where gaps exist, supplementary qualitative data will be used to triangulate findings, though this may impact the precision of performance comparisons.

Despite these limitations, the study is expected to generate meaningful insights into how Lean methodology particularly through the application of VSM can be practically implemented to optimize periodic railway vehicle maintenance. It aims to serve as a foundation for future research, including broader, multi-site studies, and support the scaling of Lean practices within the transportation sector.

References

1. Sharma, R., Kumar, S., & Jain, P. (2019). Application of lean tools in maintenance: A case study. *International Journal of Lean Systems*.
2. Womack, J. P., & Jones, D. T. (2003). *Lean thinking: Banish waste and create wealth in your corporation*. Free Press.
3. Rother, M., & Shook, J. (2009). *Learning to see: Value stream mapping to add value and eliminate Muda*. Lean Enterprise Institute.
4. Wilson, L. (2010). *How to implement lean manufacturing*. McGraw-Hill.