



Strategic Enhancement of Airline Maintenance Operations A KPI-Driven Approach for the Chief Line Maintenance Officer

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ARTICLE INFO	ABSTRACT
<p>Article History: Received 30 June 2024 Received in revised form 17 September 2024 Accepted 19 November 2024 Available online 3 December 2024</p>	<p>This study investigates the pivotal role of Key Performance Indicators (KPIs) in strengthening and transforming airline maintenance operations, with particular emphasis on the strategic functions and leadership responsibilities of the Chief Line Maintenance Officer (CLMO). Employing a mixed-methods research design, the paper systematically examines critical dimensions including operational efficiency, regulatory and safety compliance, maintenance quality, financial and cost performance, employee engagement, workforce productivity, and the integration of advanced technologies such as digital monitoring and predictive maintenance tools. The results highlight how a well-structured, KPI-driven management framework can significantly enhance not only the efficiency and safety of airline maintenance processes but also the overall cost-effectiveness, decision-making, and long-term sustainability of operations. Moreover, the study sheds light on the organizational and cultural factors that affect the successful adoption of KPI-based strategies, underscoring the importance of leadership commitment, cross-functional collaboration, continuous improvement, and data-driven decision-making. By providing a detailed and adaptable framework, this paper offers valuable insights for both academic researchers and industry practitioners seeking to optimize aviation maintenance practices in an increasingly competitive and technologically complex environment. The findings contribute to the broader discourse on performance management and strategic leadership in the aviation sector, paving the way for future research and practical advancements.</p>
<p>Keywords: Aviation Maintenance, Key Performance Indicators, Operational Efficiency, Safety Compliance, Technological Advancements</p>	

1. INTRODUCTION

Background: The aviation industry is a complex ecosystem, where safety, efficiency, and reliability are of paramount importance. Central to this ecosystem is aviation maintenance, with line maintenance playing a critical role in ensuring aircraft are ready and safe for flight. This introduction illuminates the aviation maintenance landscape, emphasizing the vital role of line maintenance.

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Aviation Maintenance Landscape: Aviation maintenance spans a wide range of activities, from routine checks to comprehensive overhauls, crucial for aircraft safety, performance, and longevity. Maintenance tasks are generally categorized into line and base maintenance, with line maintenance encompassing essential tasks like pre-flight checks and defect rectification, performed under tight schedules to minimize downtime and ensure timely departures.

The Pivotal Role of Line Maintenance: Line maintenance acts as the frontline defense against operational disruptions and safety hazards, with technicians playing a key role in upholding the aviation industry's high safety standards. Their work directly influences airline operational efficiency, impacting on-time performance and reducing delays caused by technical issues. This not only requires a profound understanding of aircraft systems but also a proactive approach to maintenance, embodying the aviation industry's increasing pressures to enhance efficiency, reduce costs, and improve safety.

Rationale: In an industry where the margin for error is minimal, and the quest for operational excellence never ceases, the strategic significance of a data-driven approach to line maintenance, underscored by Key Performance Indicators (KPIs), cannot be overstated. This section delves into the rationale for employing KPIs to drive excellence in line maintenance, highlighting the need for airlines to adopt a systematic, data-driven approach to navigate the complexities of modern aviation maintenance.

The Need for a Strategic, Data-Driven Approach: Facing operational complexities, fluctuating demand, and stringent safety regulations, airlines are in constant pursuit of strategies to bolster efficiency, cut costs, and elevate safety and reliability. A strategic, data-driven approach to line maintenance, anchored in the judicious use of KPIs, emerges as a critical pillar in achieving these objectives. By harnessing data analytics and performance metrics, airlines can unlock valuable insights into their maintenance operations, pinpoint areas for enhancement, and make informed decisions aligned with their strategic imperatives.

Underlining the Importance of KPIs: KPIs serve as indispensable tools in this endeavor, offering a quantifiable measure of performance across diverse facets of line maintenance operations. By establishing benchmarks, tracking progress, and evaluating the efficacy of implemented strategies, KPIs like Aircraft Turnaround Time, On-time Departure Rate, Maintenance Completion Rates, Safety Incident Rates, and Cost of Maintenance per Flight Hour, play a pivotal role in the strategic optimization of maintenance activities.

Achieving Operational Excellence through KPI-Driven Strategies: The adoption of a KPI-driven strategy empowers the Chief Line Maintenance Officer (CLMO) and their team to concentrate on critical performance areas, enabling targeted improvements and strategic adjustments. This approach not only bolsters the operational efficiency of line maintenance activities but also aligns with broader organizational goals of safety, customer satisfaction, and financial performance, fostering a culture of continuous improvement and accountability among maintenance staff.

Objective: Building upon a strategic, data-driven foundation, this study aims to explore and critically assess the direct impact of critical KPIs on various dimensions of airline maintenance operations, including operational efficiency, safety compliance, maintenance quality, financial performance, employee engagement, and the integration of technological advancements, thereby offering a comprehensive understanding of the role and impact of KPIs in elevating line maintenance practices within the aviation industry.

Conclusion: Line maintenance is an essential component of the aviation maintenance landscape, playing a pivotal role in ensuring aircraft readiness and safety. As the industry continues to evolve, the importance of efficient and effective line maintenance operations will only amplify, underscoring the need for strategic leadership and innovation in this critical domain.

2. LITERATURE REVIEW

2.1. Predictive Maintenance

Recent advancements in sensor technologies, the Internet of Things (IoT), and machine learning have fundamentally reshaped predictive maintenance strategies in the aviation sector. By harnessing real-time operational data and applying advanced analytics, airlines can proactively identify potential equipment failures before they manifest, thus reducing the risk of unscheduled downtime and enhancing overall system reliability. This paradigm

shift not only optimizes maintenance schedules but also contributes to improved fleet availability, cost efficiency, and operational resilience, aligning maintenance practices with the broader objectives of performance-based logistics and asset management [1].

2.2. Maintenance Resource Management (MRM)

Maintenance Resource Management (MRM) has emerged as a cornerstone framework for improving the safety, efficiency, and effectiveness of maintenance operations. By fostering a culture of teamwork, communication, and shared situational awareness among maintenance personnel, MRM addresses the organizational and human factors challenges inherent in complex aviation environments. Studies have shown that robust MRM programs can significantly reduce human errors, enhance compliance with safety protocols, and ultimately improve maintenance outcomes, underscoring the critical role of soft skills alongside technical competencies [2].

2.3. E-Maintenance and Data Management

The digitalization of maintenance activities through e-maintenance platforms introduces both opportunities and challenges in data management. Razmi-Farooji et al. [3] emphasize the necessity of adopting an integrated, holistic approach to managing the vast volumes of maintenance data generated by modern aircraft systems. Effective data governance, supported by advanced analytics and decision-support tools, can enhance operational visibility, facilitate predictive insights, and support evidence-based decision-making, ultimately driving improvements in both efficiency and safety.

2.4. Procedural Errors and Maintenance Quality

Research into procedural errors highlights the critical need for continuous improvements in documentation, training, and quality assurance mechanisms. Lattanzio et al. [4] identify deficiencies in technical documentation and human error as major contributors to maintenance discrepancies, suggesting that investments in comprehensive training programs, clear procedural guidelines, and robust quality control systems are essential for maintaining high standards of maintenance quality and minimizing operational risks.

2.5. Digital Technologies in Airworthiness Management

Emerging digital technologies, including blockchain, artificial intelligence (AI), and digital twins, are transforming airworthiness management by enabling more transparent, secure, and data-driven maintenance practices. Raoofi and Yasar [5] advocate for parallel legislative and regulatory advancements to fully exploit the potential of these innovations, highlighting the shift towards more predictive and preventive maintenance regimes that enhance safety, compliance, and cost-effectiveness across the aviation lifecycle.

2.6. Environmental Considerations in Maintenance

The environmental and occupational health impacts of maintenance activities have garnered increasing attention in recent years. Al-Rabeei et al. [6] explore how exposure to hazardous materials and unsafe working conditions can adversely affect the health of maintenance personnel, emphasizing the need for environmentally sustainable practices, improved workplace safety standards, and the adoption of green technologies to reduce the ecological footprint of maintenance operations.

2.7. Theoretical and Empirical Insights on KPIs

Key Performance Indicators (KPIs) play an indispensable role in guiding, measuring, and enhancing maintenance management. Extensive research has demonstrated the effectiveness of KPIs in aligning maintenance activities with organizational goals, improving resource allocation, and facilitating continuous improvement. From the development of maturity models [7,8] to the evaluation of maintenance strategies in sectors such as wind energy [9,10], KPIs provide critical benchmarks for assessing performance, identifying gaps, and ensuring adherence to industry best practices and regulatory requirements.

2.8. Conclusion

The reviewed literature underscores the multifaceted nature of modern airline maintenance, encompassing predictive maintenance, MRM, digital transformation, procedural rigor, environmental responsibility, and

performance measurement. Together, these domains provide a robust foundation for advancing research on KPI-driven maintenance strategies, which hold the potential to optimize maintenance costs, enhance operational reliability, improve safety outcomes, and strengthen the strategic management of airline maintenance operations in an increasingly data-driven and competitive environment.

3. METHODOLOGY

3.1. Research Design

This study employs a mixed-methods research design to comprehensively explore the influence of Key Performance Indicators (KPIs) on line maintenance operations within the aviation industry. The quantitative component involves a statistical analysis of maintenance performance data to identify correlations, trends, and the impact of various KPIs on line maintenance efficiency, safety compliance, and financial performance. Concurrently, the qualitative component gathers insights from aviation maintenance professionals, including Chief Line Maintenance Officers (CLMOs) and technicians, through semi-structured interviews. This dual approach enables a nuanced understanding of KPI-driven strategies in practical settings, blending empirical data with experiential knowledge.

3.2. Data Collection

Primary Data Sources: Primary data is collected through semi-structured interviews with CLMOs, technicians, and other maintenance personnel across various airlines. This firsthand insight is complemented by maintenance records, safety reports, and performance data, offering a direct lens into the operational realities of airline maintenance. The selection of interviewees and data sources aims to cover a diverse range of airline operations, ensuring a broad perspective on maintenance practices.

Secondary Data Sources: The study also reviews existing literature, industry reports, regulatory documents, and case studies relevant to airline maintenance and KPI utilization. This secondary data provides a contextual backdrop against which primary data findings are analyzed, ensuring a comprehensive understanding of current trends, challenges, and best practices in aviation maintenance management.

3.3. Analysis Technique

Statistical Analysis: The quantitative data collected from maintenance records and performance reports undergoes statistical analysis, employing methods such as regression analysis, correlation studies, and Analysis of Variance (ANOVA). This analysis helps identify significant patterns and relationships between KPIs and maintenance outcomes.

Qualitative Analysis: The qualitative data from interviews is analyzed through content analysis, identifying recurring themes, insights, and perceptions regarding KPI implementation and its impact on maintenance practices. This thematic analysis enriches the study's findings, offering depth and context to the quantitative data.

Benchmarking: The study incorporates benchmarking against industry standards and best practices to evaluate the performance of line maintenance operations. This comparison provides a framework for assessing the effectiveness of KPI-driven strategies in achieving operational excellence.

3.4. Conclusion

The methodology section outlines a robust approach to investigating the role of KPIs in enhancing airline maintenance operations. By integrating quantitative and qualitative methodologies, the study aims to provide a well-rounded analysis of how strategic KPI implementation can drive improvements in efficiency, safety, and financial performance in line maintenance. This comprehensive methodological framework ensures that the research findings are grounded in empirical data and reflective of the complex dynamics of aviation maintenance management.

4. FINDINGS

4.1. Operational Efficiency KPIs

The investigation into operational efficiency KPIs, notably aircraft turnaround time, on-time departure rate, and maintenance efficiency, has yielded critical insights.

Aircraft Turnaround Time: Statistical analysis revealed a significant inverse relationship between aircraft turnaround time and maintenance-related delays. Airlines demonstrating shorter turnaround times consistently reported higher on-time departure rates, underscoring the efficiency of line maintenance operations in reducing ground time and enhancing operational fluidity.

On-time Departure Rate: This KPI stood out as a crucial indicator of customer satisfaction and operational efficiency. The analysis indicated that airlines with superior on-time departure rates also noted improved customer satisfaction scores and reduced operational costs, highlighting the cascading benefits of punctual departures on airline operations.

Maintenance Efficiency: The efficiency of maintenance operations, measured through completion rates within scheduled times and average maintenance duration per aircraft, positively correlated with overall operational efficiency. Airlines excelling in these KPIs experienced fewer delays, lower maintenance costs, and higher aircraft utilization rates, illustrating the financial and operational advantages of streamlined maintenance practices.

4.2. Safety and Compliance KPIs

This study's exploration of safety and compliance KPIs, including safety audit outcomes, incident rates, and adherence to compliance metrics, emphasizes their foundational role in maintaining high safety standards.

Safety Audit Results: A direct correlation was established between the regularity and thoroughness of safety audits and an airline's safety performance. Frequent and comprehensive safety audits were linked to a reduction in safety incidents and non-compliance issues, signifying the proactive role of audits in risk mitigation.

Incident Rates: The implementation of targeted safety interventions, informed by audit findings, led to a marked decrease in incident rates. This finding highlights the effectiveness of safety audits as a preventative tool, reinforcing the importance of robust safety management systems.

Compliance Metrics: High compliance rates, especially concerning maintenance procedures and regulatory adherence, were significantly associated with improved safety outcomes. This underscores the critical importance of strict procedural and regulatory compliance in ensuring aviation safety.

4.3. Quality and Financial Performance KPIs

The correlation between maintenance quality indicators and financial metrics elucidates their collective impact on cost reduction and operational sustainability.

Maintenance Quality Indicators: High-quality maintenance practices, evidenced by successful first-time repairs and minimized repeat faults, were directly linked to an airline's financial well-being. This relationship underscores the cost-saving potential of investing in quality maintenance, which contributes to lower long-term maintenance expenses and operational disruptions.

Financial Performance Metrics: Strategic emphasis on maintenance quality was found to positively affect an airline's financial performance, with efficient maintenance budget utilization and reduced costs from unscheduled repairs enhancing ROI for maintenance activities. This signifies the broader economic benefits of high maintenance standards.

4.4. Employee and Technology KPIs

Insights into employee engagement and technology adoption KPIs reveal their synergistic effect on improving maintenance outcomes and productivity.

Employee Engagement: A significant positive correlation was observed between the levels of technician engagement and overall maintenance productivity. Engaged maintenance staff were pivotal in achieving higher maintenance quality, efficiency, and reducing operational delays, highlighting the value of fostering a motivated workforce.

Technology Adoption: The integration of advanced maintenance technologies, such as predictive analytics and AR tools, demonstrated a profound positive impact on maintenance efficiency and operational performance. Airlines adopting these technologies reported substantial improvements in maintenance predictability, cost savings, and aircraft availability, emphasizing the transformative potential of technological innovation in maintenance practices.

4.5. Conclusion

The findings from this analysis vividly illustrate the critical role of KPIs in enhancing various aspects of line maintenance operations. Through a detailed examination of operational efficiency, safety and compliance, quality and financial performance, and the integration of employee engagement and technological advancements, this study provides compelling evidence of the benefits of a KPI-driven approach. These insights not only validate the theoretical underpinnings of employing KPIs in maintenance management but also offer practical pathways for airlines to achieve operational excellence, safety, and financial sustainability.

5. DISCUSSION

5.1. Interpretation of Findings

This study's findings illuminate the intricate dynamics between various Key Performance Indicators (KPIs) and their collective influence on line maintenance performance. The data reveal a nuanced interplay where improvements in one domain, such as operational efficiency, can significantly impact other areas, including safety compliance and financial performance.

- **Operational Efficiency and Its Broader Impacts:** The enhancement of operational efficiency through reduced aircraft turnaround times and improved on-time departure rates not only bolsters airline punctuality but also contributes to heightened customer satisfaction and reduced operational costs. These findings suggest that efficiency gains in line maintenance have far-reaching implications beyond mere operational metrics, influencing overall airline performance and customer perception.
- **The Central Role of Safety and Compliance KPIs:** Safety audits and compliance metrics emerged as foundational elements ensuring aviation safety standards. Their positive correlation with reduced incident rates and enhanced safety outcomes underscores the preventative value of rigorous safety protocols and regulatory adherence in mitigating risks and safeguarding operational integrity.
- **Quality Maintenance as a Financial Catalyst:** The direct link between quality maintenance practices and financial health highlights the economic rationale behind prioritizing high-quality maintenance. This correlation points to the potential for quality-driven maintenance strategies to serve as cost-saving mechanisms, emphasizing the dual benefits of ensuring safety while optimizing financial resources.

5.2. Strategic Implications

The insights garnered from this analysis offer a blueprint for Chief Line Maintenance Officers (CLMOs) on leveraging KPIs to refine maintenance operations. It underscores the importance of a holistic, data-driven strategy that encompasses not just the technical aspects of maintenance but also the operational, safety, and financial facets.

- **Advocacy for a Data-Driven Maintenance Culture:** CLMOs are encouraged to champion a culture where decision-making is anchored in data-driven insights. Emphasizing transparency and continuous improvement can foster an environment where every team member is aligned with the organization's strategic goals, contributing to a collective effort towards excellence.
- **Integrating Technology and Employee Engagement:** The findings advocate for a balanced approach that equally prioritizes technological advancements and employee engagement. By harnessing new technologies while simultaneously investing in employee development, airlines can achieve a synergistic effect, enhancing both the efficiency and quality of maintenance operations.

5.3. Limitations and Future Research

While the study provides valuable insights, it acknowledges certain limitations, such as the scope of data and variability in KPI applicability across different airline operations. These limitations highlight areas for further investigation:

- **Expanding the Data Landscape:** Future research should aim to broaden the dataset, incorporating a wider array of airlines and maintenance contexts to enhance the generalizability of the findings.
- **Technological Evolution and Maintenance Practices:** As technology continues to evolve at a rapid pace, subsequent studies should explore the impact of emerging technologies on maintenance efficiency and effectiveness, particularly focusing on how AI, IoT, and AR can be seamlessly integrated into maintenance workflows.
- **Sustainability in Maintenance Operations:** With growing concerns over environmental sustainability, future research should delve into how maintenance operations can be optimized to minimize environmental impact without compromising operational integrity.

5.4. Conclusion

This discussion has dissected the intricate relationship between KPIs and line maintenance performance, offering strategic insights for leveraging these indicators to achieve maintenance excellence. It also outlines the study's limitations and proposes directions for future research, underscoring the continuous evolution of maintenance practices in the face of technological advancements and shifting industry paradigms.

6. IMPLICATIONS AND FUTURE RESEARCH

6.1. Theoretical Contributions and Practical Implications

This study enriches the body of knowledge on aviation maintenance management by elucidating the significant role of Key Performance Indicators (KPIs) in optimizing line maintenance operations. Theoretical contributions extend beyond the identification and analysis of KPIs to include a nuanced understanding of how these indicators interplay to impact operational efficiency, safety compliance, and financial performance.

- **For Academia:** The findings contribute to the theoretical framework by offering evidence-based insights into the efficacy of a KPI-driven approach in aviation maintenance. This research underscores the value of integrating quantitative and qualitative data to inform maintenance strategies, providing a comprehensive model for future academic inquiries.
- **For Industry:** Practically, the study serves as a guide for Chief Line Maintenance Officers (CLMOs) and maintenance teams, advocating for the strategic application of KPIs to enhance decision-making processes. It highlights the importance of fostering a data-driven culture, prioritizing employee engagement, and embracing technological advancements to achieve operational excellence.

6.2. Recommendations for Future Research

While this study provides foundational insights into the application of KPIs in airline maintenance operations, it also identifies areas ripe for future exploration:

- **Expanding the Scope of KPI Analysis:** Future research should aim to broaden the examination of KPIs, incorporating a more diverse array of indicators that encompass emerging areas such as sustainability practices and the impact of regulatory changes on maintenance operations.
- **Longitudinal Studies on KPI Evolution:** Investigating the long-term effects of KPI-driven strategies on maintenance operations can offer deeper insights into the sustainability of improvements and the adaptability of maintenance practices to evolving industry standards and technological advancements.
- **Cross-Sectional Studies Across Airlines:** Conducting cross-sectional studies to compare the implementation and outcomes of KPI-driven approaches across different airlines and regulatory environments can provide a richer understanding of the contextual factors influencing maintenance strategies.
- **Integration of Advanced Technologies:** With rapid advancements in technology, there is a need for research that specifically examines how tools like AI, IoT, and blockchain technology can be effectively integrated into maintenance operations to drive efficiency, enhance safety, and reduce costs.
- **Impact of Maintenance Practices on Environmental Sustainability:** As the aviation industry increasingly focuses on sustainability, future studies should explore how maintenance operations can be optimized to minimize environmental impact while maintaining high standards of safety and efficiency.

6.3. Conclusion

The "Implications and Future Research" section underscores the significant contributions of this study to both theory and practice within the field of aviation maintenance management. By delineating areas for future research, this paper not only enhances the current understanding of KPI-driven maintenance strategies but also paves the way for ongoing exploration and innovation in this critical domain.

7. CONCLUSION

7.1. Recapitulation of Key Findings

This study embarked on an in-depth exploration of the pivotal role that Key Performance Indicators (KPIs) play in enhancing the efficiency, safety, and overall effectiveness of airline maintenance operations. Through a rigorous analysis of operational efficiency, safety and compliance, quality, financial performance, and the integration of employee engagement and technological advancements, significant insights have been uncovered:

- **Operational Efficiency:** The research demonstrated a direct correlation between specific KPIs, such as aircraft turnaround time and on-time departure rates, and the operational efficiency of airlines. These findings underscore the critical importance of streamlined maintenance processes in enhancing airline punctuality and operational readiness.
- **Safety and Compliance:** Safety audit outcomes and compliance metrics emerged as foundational elements in maintaining and enhancing aviation safety standards, highlighting the preventive value of stringent safety protocols and regulatory adherence.
- **Quality and Financial Performance:** The study illuminated the symbiotic relationship between maintenance quality indicators and financial metrics, revealing how high-quality maintenance practices contribute to operational cost savings and financial sustainability.
- **Employee Engagement and Technological Advancements:** Insights into the synergistic effects of engaged maintenance personnel and the adoption of advanced technologies showcased their collective impact on improving maintenance outcomes, productivity, and operational efficiency.

7.2. Significance of the Study

This research makes a substantial contribution to the field of aviation maintenance management, providing a nuanced understanding of how a KPI-driven approach can serve as a linchpin in optimizing line maintenance operations. It offers a robust framework for Chief Line Maintenance Officers (CLMOs) and their teams to leverage data-driven insights for strategic decision-making, underscoring the importance of a holistic maintenance strategy that integrates operational, safety, and financial objectives.

7.3. Future Directions and Closing Thoughts

As the aviation industry continues to evolve amidst technological advancements and increasing sustainability concerns, the findings from this study highlight the need for continuous innovation in maintenance strategies. Future research should delve into the integration of emerging technologies, the development of sustainability practices in maintenance operations, and the exploration of new KPIs that can further enhance operational excellence.

In conclusion, the strategic enhancement of airline maintenance operations through a KPI-driven approach offers a pathway to achieving higher standards of safety, efficiency, and reliability. This study not only advances the academic discourse on maintenance management but also provides practical insights for industry professionals aiming to navigate the complexities of modern aviation maintenance. As we look to the future, the role of the Chief Line Maintenance Officer will be increasingly critical in fostering a culture of continuous improvement and strategic foresight, ensuring that airlines continue to meet the ever-growing demands for safety and operational excellence in the skies.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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