

**Integrated Runway Friction and Rubber Management:
Balancing Safety, Asphalt Deterioration, and Maintenance Funding Efficiency**

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Abstract

Runway surface friction is a critical determinant of aerodrome safety, particularly under wet or contaminated conditions when the risk of runway excursions increases. Repeated aircraft landings lead to rubber accumulation concentrated in touchdown zones, reducing microtexture, impairing drainage, and lowering measured friction. To maintain safe operations, aerodromes routinely conduct friction testing and derubberisation in accordance with ICAO and GACA requirements, guided by reference thresholds such as the Design Friction Level (DFL), Maintenance Planning Level (MPL), and Minimum Friction Level (MFL). However, when derubberisation is performed too frequently without data-driven justification, or is improperly executed (e.g., excessive water pressure or unsuitable techniques), it may accelerate asphalt deterioration, reduce pavement life, and increase long-term rehabilitation costs.

This study proposes an integrated runway friction and rubber management framework that balances operational safety, pavement preservation, and maintenance funding efficiency. Using operational data from an anonymized aerodrome with a dual-runway main/standby configuration, the research will analyze friction test trends, flight-traffic characteristics, derubberisation practices, and indicative maintenance costs. The aim is to quantify relationships between traffic, friction deterioration (DFL–MPL–MFL), removal patterns, and pavement condition, and to compare reactive, threshold-triggered maintenance with predictive, data-driven strategies. The expected outcome is a practical decision-support model to help aerodrome maintenance managers sustain regulatory compliance while optimizing pavement life and the use of limited maintenance resources.

1. Introduction

Runway surface condition is one of the most influential factors affecting the safety and operational reliability of an aerodrome. Aircraft depend on adequate friction during landing and takeoff to maintain braking effectiveness, ensure directional stability, and prevent runway excursions. Insufficient friction increases stopping distance, reduces lateral control, and elevates the risk of veering off or overrunning the runway. For these reasons, ICAO and national authorities such as the General Authority of Civil Aviation (GACA) require airports to continuously monitor and manage runway friction.

One of the primary causes of friction reduction is the progressive accumulation of rubber deposits from aircraft tires, particularly in touchdown zones. When tires make initial runway contact during landing, they rapidly spin up from zero rotational speed to match ground speed. This brief slipping phase generates heat that softens the rubber, causing it to bond to the pavement. With each landing, additional layers of rubber accumulate, gradually forming a film that smooths the pavement's microtexture, reduces tire-pavement interlock, and impedes water drainage. The result is a measurable decline in friction, especially under wet conditions.

ICAO guidance—such as Annex 14 and Airport Services Manual (Doc 9137)—along with GACA regulations, outlines the aerodrome's responsibility to monitor runway friction using Continuous Friction Measuring Equipment (CFME). Friction results must be evaluated against three reference thresholds:

- **Design Friction Level (DFL):** Expected friction level after resurfacing or maintenance.
- **Maintenance Planning Level (MPL):** The level at which planning and scheduling of maintenance should begin.
- **Minimum Friction Level (MFL):** The minimum acceptable friction level; falling below this requires immediate corrective action and possible operational restrictions.

These thresholds, applied to 100-metre runway segments, help identify localized friction deficiencies in touchdown and rollout zones.

To restore friction, aerodromes perform periodic rubber removal using techniques such as high-pressure water jetting, chemical treatments, or mechanical methods. While effective, these techniques can accelerate asphalt deterioration if not performed carefully. Excessive water pressure, aggressive mechanical action, or inappropriate chemicals may cause binder stripping, raveling, microcracking, or macrotexture loss.

Managing runway friction is therefore a balancing act involving three interconnected dimensions:

- **Operational safety** — maintaining friction above regulatory thresholds.
- **Engineering performance** — minimizing pavement deterioration and extending runway life.
- **Financial sustainability** — optimizing maintenance costs and avoiding premature rehabilitation.

In many aerodromes, friction management decisions remain reactive. Friction tests are performed at required intervals, and maintenance is triggered only after values fall below MPL or MFL. This approach meets minimum regulatory obligations but does not leverage trends or predictive insights. It may also lead to over-frequent derubberisation, premature pavement wear, and increased long-term costs.

This research addresses the need for a more integrated, data-driven approach that links flight-traffic characteristics, friction trends, derubberisation practices, pavement deterioration, and maintenance costs. By analyzing real operational data from a dual-runway aerodrome (operating one runway at a time in main/standby mode), the study aims to develop a practical framework that supports safer, more efficient, and financially sustainable runway maintenance planning.

Although the aerodrome consists of two runways, they are not parallel and therefore cannot support simultaneous independent operations. In practice, one runway functions as the primary active runway while the other remains on standby, maintenance, or contingency use. This operational context informs the analysis of friction trends and rubber accumulation.

2. Problem Statement

Effective runway friction and rubber management is essential for maintaining safe aerodrome operations. ICAO and GACA provide clear guidance on friction measurement, evaluation thresholds, and required maintenance actions. Yet, despite the existence of these standards, aerodromes continue to face challenges that affect both safety and long-term pavement performance.

A primary challenge is the prevalence of **reactive maintenance**, where corrective action is taken only after friction drops below the Maintenance Planning Level (MPL) or Minimum Friction Level (MFL). While this ensures basic compliance, it does not consider friction trends, deterioration rates, or predictive insights that could improve planning, reduce operational disruptions, and avoid last-minute interventions.

A second challenge relates to **derubberisation practices**. Overly frequent removal or improperly executed techniques—such as excessive water pressure, unsuitable chemical agents, or aggressive mechanical methods—can accelerate asphalt deterioration. This contributes to binder stripping, microcracking, aggregate loss, and an earlier need for resurfacing or other major rehabilitation works.

The result is a paradox: **attempts to maintain friction and uphold safety can unintentionally shorten pavement life**, increase maintenance costs, and place additional pressure on aerodrome budgets. Additionally, rubber accumulation and friction deterioration vary depending on aircraft weight mix, landing frequency, seasonal patterns, and runway-end usage. These relationships are rarely quantified or incorporated into maintenance decision-making.

Existing literature and operational standards address friction thresholds, pavement deterioration mechanisms, and cost considerations—but typically **in isolation**. Very few studies integrate:

- flight-traffic characteristics
- friction performance (DFL–MPL–MFL)
- derubberisation patterns
- pavement condition
- maintenance and rehabilitation cost drivers

into a single framework tailored for aerodrome use.

Thus, aerodrome operators lack a comprehensive, evidence-based model that enables them to shift from reactive to predictive maintenance. Without such a model, they risk continuing cycles of over-frequent interventions, premature deterioration, and escalating maintenance expenditures.

In summary:

There is currently **no integrated, data-driven framework** that links traffic characteristics, friction thresholds, rubber removal practices, pavement deterioration processes, and maintenance funding requirements into a unified model for optimized runway maintenance planning.

3. Aim and Objectives of the Study

3.1 General Aim

To develop an integrated runway friction and rubber management framework that balances operational safety, asphalt deterioration, and maintenance funding efficiency in accordance with ICAO and GACA requirements.

3.2 Specific Objectives

To achieve this overall aim, the study will pursue the following specific objectives:

1. **Analyze** the relationship between flight-traffic characteristics and friction performance trends, by examining how daily turbojet landings, aircraft weight mix, and runway-end usage patterns influence friction test results evaluated against the DFL, MPL, and MFL thresholds.
2. **Evaluate** the impact of rubber removal frequency, method, and execution quality on asphalt deterioration, by assessing how differences in operation timing, pressure, chemical use, and technique correlate with observed changes in pavement texture and condition.
3. **Compare** reactive and predictive maintenance approaches in terms of operational and financial outcomes, focusing on how the timing and justification of rubber removal influence pavement service life and overall maintenance expenditure.

4. **Estimate** maintenance and rehabilitation costs associated with different friction and rubber management strategies, using available records and standard engineering unit rates to build representative cost profiles.
 5. **Propose and validate** a practical, data-driven decision-support model that integrates safety, engineering, and financial indicators to guide aerodrome managers in optimizing runway maintenance planning.
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4. Research Questions and Hypotheses

4.1 Research Questions

Based on the problem statement and objectives, the study will seek to answer the following questions:

1. How do flight-traffic characteristics influence friction deterioration and the timing of maintenance interventions?
2. What is the relationship between rubber removal frequency, chosen methods, and asphalt deterioration patterns?
3. How do reactive maintenance practices compare with predictive, data-driven approaches in terms of safety, pavement condition, and cost?
4. To what extent can optimized friction and rubber management reduce the frequency and cost of major rehabilitation and resurfacing works?
5. How can an integrated framework that combines operational, engineering, and financial variables support better runway maintenance decision-making?

4.2 Hypotheses

The study will test the following hypotheses:

- **H1:** There is a significant correlation between flight-traffic intensity and friction performance trends, such that higher traffic and heavier aircraft are associated with faster friction decline.

- **H2:** Excessive or improperly executed rubber removal operations significantly increase the rate of asphalt deterioration and reduce pavement service life.
 - **H3:** Predictive, data-based maintenance planning yields greater cost efficiency and better pavement over time than reactive, threshold-triggered maintenance.
 - **H4:** Optimized friction and rubber management strategies lead to measurable reductions in the frequency and cost of major runway rehabilitation and resurfacing works.
 - **H5:** An integrated management framework that incorporates safety, engineering, and financial indicators improves the effectiveness and transparency of maintenance decision-making.
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5. Significance of the Study

This study offers value across several dimensions:

5.1. Operational Safety

By linking traffic characteristics with friction trends, the study enhances an aerodrome's ability to anticipate friction degradation before it reaches critical levels. This helps reduce excursion risk and strengthens wet-runway performance management.

5.2. Engineering and Pavement Management

The study provides insight into how derubberisation practices influence deterioration, particularly in hot climates where asphalt oxidation is prevalent. Findings can guide the selection of removal techniques that restore friction while minimizing surface damage.

5.3. Financial and Managerial Impact

Runway rehabilitation is costly and operationally disruptive. By demonstrating how predictive strategies can extend pavement life and optimize maintenance timing, the study offers operators a stronger basis for budget justification and resource allocation.

5.4. Regulatory and Institutional Value

The study aligns operational data with the intent of ICAO and GACA standards, contributing practical tools that go beyond minimum regulatory requirements and enhance long-term compliance. The framework also strengthens alignment with GACAR Part 139 requirements for continuous runway monitoring and proactive maintenance planning, enhancing the aerodrome's institutional compliance posture

5.5. Academic Contribution

Few studies integrate friction performance, rubber accumulation, pavement deterioration, and cost considerations into a single model. This research addresses that gap and contributes to aviation asset-management literature.

6. Scope and Limitations of the Study

6.1. Scope

6.1.1. Spatial Scope:

The study focuses on an anonymized aerodrome with **two non-parallel runways**, operated in a **main/standby configuration**. Only one runway is active at a time, while the other supports maintenance or remains on standby. Friction, rubber accumulation, and maintenance activities on both runways will be analyzed to the extent permitted by available data. Runway identifiers and airport name will not be disclosed. Although the aerodrome consists of two runways, they are not parallel and cannot be used simultaneously for independent operations. Practically, one runway functions as the primary active runway while the other serves as a standby. Therefore, the study analyzes friction performance and rubber management on the runway in active operational use during each period.

6.1.2. Temporal Scope:

The analysis will primarily cover a period of approximately 12 to 24 months of operational and maintenance history, depending on data availability. This timeframe is chosen to

capture seasonal variations and to provide a sufficient number of friction tests and maintenance cycles for meaningful analysis.

6.1.3. Thematic Scope:

The study focuses on friction performance, rubber accumulation, derubberisation practices, pavement condition, and cost considerations. Other aerodrome elements (geometry, lighting, drainage) will be referenced only when directly affecting friction or maintenance.

6.2. Limitations

6.2.1. Data Completeness

Cost data may lack full historical detail. When required, standardized engineering rates and documented assumptions will be used to produce consistent estimates.

6.2.2. Runway System Dynamics

Because only one runway operates at a time, rubber accumulation and deterioration patterns differ between the main and standby runways. Comparative detail may be limited by available data.

6.2.3. Generalizability

Findings reflect a dual-runway aerodrome in a specific environment. The proposed framework is adaptable, but results may vary in airports with different climates or traffic mixes.

6.2.4. Observational Data

The study relies on operational records rather than controlled experiments. Causal relationships will be inferred through correlation, sequence analysis, and engineering judgment.

6.2.5. Confidentiality Requirements

In compliance with ICAO/GACA confidentiality standards, all identifying details will be anonymized. This limits descriptive specificity but does not affect analysis quality.

7. Literature Review

Runway friction, rubber accumulation, pavement deterioration, and maintenance funding strategies intersect across several areas of aviation safety, pavement engineering, and asset management. Although these domains are well established individually, the literature reveals that comprehensive integration among them remains limited. This review explores the major themes relevant to the study: (1) runway friction and safety performance, (2) mechanisms of rubber accumulation and characteristics of removal methods, (3) asphalt pavement deterioration under maintenance stress, (4) reactive versus predictive maintenance strategies, and (5) financial implications and life-cycle cost planning. The review highlights gaps in existing research that justify the need for an integrated framework.

7.1 Runway Friction and Safety Requirements

The importance of runway friction as a determinant of aircraft braking and directional control is well documented across aviation literature. International and national regulators characterize friction as a fundamental safety parameter, particularly in wet conditions when the coefficient of friction naturally decreases. ICAO Annex 14 outlines the criteria for acceptable friction levels and introduces the three widely used thresholds (DFL, MPL, MFL). These levels are used together with 100-metre segment analysis to identify localized friction deficiencies in line with ICAO guidance. This 100-metre segmentation is intended for maintenance assessment, whereas operational reporting under GRF uses runway third-based Runway Condition Codes (RWYCC). It is important to distinguish that 100-metre segmentation is used for maintenance assessment under ICAO Annex 14 and Doc 9137, while operational runway condition reporting under the Global Reporting Format (GRF) relies on runway thirds (RWYCC).

Studies in aviation safety emphasize that friction reduction is directly correlated with runway excursion risk. Accident investigation reports frequently note that inadequate friction, combined with wet or contaminated conditions, contributed to extended stopping distances or loss of directional control. These findings reinforce the need for systematic friction monitoring and timely corrective action.

The literature also underscores that friction performance is dynamic rather than static. Seasonal patterns, traffic intensity, aircraft weight, environmental conditions, and pavement texture all contribute to natural fluctuations. Continuous Friction Measuring Equipment (CFME), such as

Mu-Meter, GripTester, and ASFT devices, are commonly used to quantify friction along runway segments. Empirical studies compare these devices' repeatability, environmental sensitivity, and suitability for different runway surfaces, highlighting that device selection and calibration influence measured values.

A recurring conclusion is that friction values must be interpreted in context. Single measurements, without consideration of preceding trends, traffic conditions, or recent maintenance activities, can be misleading. Yet many aerodromes still rely on periodic, fixed-interval friction testing and respond only when a measurement drops below a reference level, rather than using trends to guide predictive planning.

7.2 Rubber Accumulation: Mechanisms and Effects

The formation of rubber deposits on runway surfaces has been studied extensively in both pavement and safety literature. When an aircraft lands, the tires experience a short but intense period of slip as they synchronize with ground speed. This generates heat and shear forces, softening the rubber and causing it to bond to the pavement surface. Over time, repeated landings build up a rubber layer, especially in touchdown zones where most aircraft make initial contact.

This rubber layer negatively affects friction by smoothing the surface and filling microtexture. It also impedes the drainage of water, increasing the risk of hydroplaning and reducing braking efficiency. As the rubber layer thickens, friction values measured by CFME typically decline, particularly under wet conditions.

Despite strong understanding of the basic mechanism, fewer studies quantify the rate at which rubber accumulates as a function of flight-traffic characteristics. Some regulatory and technical documents note that heavy aircraft, high tire pressures, and frequent operations accelerate accumulation, but detailed analytical models are scarce. This lack of quantified relationships between traffic and rubber buildup complicates efforts to design optimal maintenance intervals.

7.3 Rubber Removal Methods and Their Pavement Impacts

The literature identifies three principal categories of rubber removal methods:

1. High-pressure water jetting.
2. Chemical or enzymatic treatments.

3. Mechanical removal (e.g. shot-blasting, grinding).

Each technique has distinct advantages and risks.

High-pressure water jetting is widely used due to its effectiveness and avoidance of chemical residues. Case studies and experimental work show that, when properly controlled, it can restore friction to near-design levels. However, several studies also report that excessive pressure, inappropriate nozzle angles, or repeated passes can dislodge aggregate, strip binder, and erode macrotexture—especially on older or oxidized asphalt.

Chemical or enzymatic treatments work by softening or breaking down rubber, which is then removed by brushing or low-pressure washing. When correctly applied, these methods can be less mechanically aggressive, potentially preserving surface texture. However, concerns exist about chemical interaction with binder components, environmental impacts of runoff, and residue if rinsing is insufficient. These concerns have led some regulators to impose restrictions on certain chemicals.

Mechanical methods such as shot-blasting are powerful but highly aggressive. They may be appropriate for severe buildup or specific situations, but they can significantly change texture and may introduce micro-damage that accelerates raveling. As a result, most guidance recommends using such methods sparingly.

Overall, the literature agrees that poorly controlled or overly frequent rubber removal can significantly accelerate pavement deterioration. Yet many aerodromes do not systematically record removal settings, making it difficult to analyze long-term effects.

7.4 Pavement Deterioration and Texture Loss

Asphalt pavement deterioration is a complex process. Key mechanisms include oxidation (hardening and embrittlement of the binder), raveling (loss of aggregate), stripping (loss of adhesion between binder and aggregate), rutting (permanent deformation), and cracking. Texture loss, both microtexture and macrotexture, is particularly relevant to friction.

Pavement engineering literature provides models for how deterioration progresses under traffic and environmental exposure, but relatively few studies focus specifically on the impact of maintenance actions themselves on deterioration rates. In hot-climate regions, such as the Middle

East, asphalt is more susceptible to thermal effects, and repeated exposure to high-pressure water or mechanical stress during rubber removal can exacerbate stripping and raveling.

Several field studies suggest that pavements subjected to aggressive or frequent rubber removal show earlier onset of surface defects compared to comparable pavements with more moderate maintenance regimes. However, these findings are often case-specific, and there is a lack of generalized models that incorporate removal practices as a distinct deterioration factor.

7.5 Reactive vs Predictive Maintenance Approaches

Across infrastructure sectors, maintenance strategies are commonly categorized into reactive, preventive, and predictive approaches. Reactive maintenance responds to failures or threshold exceedances after the fact. Preventive maintenance is scheduled at fixed intervals, regardless of actual condition. Predictive maintenance uses condition monitoring and trend analysis to plan interventions before serious problems occur, with the goal of optimizing performance and cost.

In the context of runway friction and rubber management, most case descriptions in the literature indicate a strong reliance on reactive strategies. Friction tests are performed at intervals prescribed by regulation or local practice. When measured values fall below MPL or MFL, corrective action—usually rubber removal—is triggered. While this approach satisfies the minimum regulatory requirement, it does not exploit the full potential of data to anticipate future needs or to coordinate maintenance with other activities.

Predictive approaches for runway maintenance, inspired by pavement management systems used in highway agencies, have begun to appear in some studies. These approaches use historical friction data, traffic volumes, and condition indices to forecast when friction is likely to decline to critical levels, allowing maintenance to be scheduled in advance and integrated into broader work programs. However, such models are not yet widely applied, and many do not include financial considerations in a structured way.

7.6 Life-Cycle Costs, Funding Efficiency, and Economic Implications

Life-cycle cost analysis (LCCA) is a well-established tool in pavement management. It evaluates the total cost of owning and maintaining an asset over a defined period, incorporating initial construction, routine maintenance, rehabilitation, and residual value. In highway and urban road

networks, LCCA is widely used to compare design alternatives and to justify investment in preservation treatments.

In the aviation context, literature and guidance documents acknowledge the high cost and operational impact of runway rehabilitation. However, relatively few studies apply full LCCA methods to compare friction and rubber management strategies. Many cost analyses focus on individual interventions—such as a single overlay or a specific rubber removal contract—rather than on the cumulative effects of repeated maintenance cycles and accelerated deterioration.

Economic modeling suggests that premature deterioration caused by aggressive or poorly planned maintenance can significantly reduce the return on investment in pavement infrastructure. Extending pavement life by even a few years can yield substantial cost savings, especially in major airports. Yet, without a framework that explicitly links maintenance actions to life-cycle costs, it is difficult for aerodrome managers to demonstrate these benefits and secure support for changes in strategy.

7.7 Synthesis and Gap Identification

The literature provides abundant knowledge about the individual elements of runway friction and pavement management. However, it also reveals important gaps:

- Flight-traffic intensity and aircraft weight mix are recognized as contributors to rubber accumulation and friction decline, but quantitative relationships are not well developed.
- The impact of rubber removal methods and frequency on long-term pavement deterioration is acknowledged but insufficiently modeled, particularly in hot-climate environments.
- The contrast between reactive and predictive friction management is conceptually recognized, but empirical studies in real operational settings are limited.
- Most importantly, safety performance (friction), engineering behavior (deterioration), and financial outcomes (cost) are usually analyzed separately. Very few studies integrate these dimensions into a single, practical decision-support framework for aerodrome use.

This study aims to address these gaps by examining how friction trends, traffic patterns, removal practices, and cost implications interact in practice, and by proposing an integrated model that can guide runway friction and rubber management in a more holistic and sustainable way.

Despite extensive international guidance from ICAO and GACA on friction measurement, rubber removal, and pavement maintenance, none of these documents provides an integrated operational–engineering–financial model. As a result, aerodrome operators lack a structured methodology for balancing safety compliance with long-term pavement preservation and funding efficiency.

8. Theoretical and Conceptual Framework

The theoretical framework for this study is built on three main pillars: safety theory, pavement engineering theory, and financial/asset management theory.

8.1. Safety perspective,

Runway friction is treated as a key performance indicator that directly influences risk. ICAO friction thresholds (DFL, MPL, MFL) can be interpreted as operational risk boundaries. Operating above DFL implies a conservative safety margin, while operating between MPL and MFL requires increased attention and planning. Operating below MFL indicates an unacceptable risk level that demands urgent corrective action and possibly operational restrictions. In this view, friction is not just a physical measure but a proxy for safety performance and maintaining friction above minimum thresholds is a core risk-control measure.

8.2. Pavement Engineering perspective:

The runway is regarded as a structural and functional asset subject to deterioration over time. Rubber removal is modeled as a maintenance action that has both positive and negative effects: it restores surface friction (functional performance) but may also contribute to surface damage and accelerated deterioration (structural and functional degradation) if not properly managed. Pavement deterioration models help explain how repeated exposure to high-pressure water, thermal cycles, and mechanical brushing affects binder properties, texture depths, and the onset of surface defects.

8.3. financial and asset management perspective:

Maintenance and rehabilitation are viewed as investments. The objective is to minimize the total cost of providing the required level of service over the pavement’s life, rather than minimizing the cost of individual interventions. Life-cycle cost thinking encourages decision-makers to consider

how current maintenance choices influence future rehabilitation needs and the overall economic performance of the runway asset. In this study, maintenance funding efficiency is not interpreted simply as “spending less,” but rather as spending wisely in ways that maintain safety and extend pavement life.

Conceptually, the framework links these three pillars through cause–effect relationships:

- Flight-traffic variables (e.g. daily landings, aircraft weight mix) influence the rate of rubber accumulation and thus the rate of friction deterioration.
- Friction behavior is monitored by CFME and evaluated against DFL, MPL, and MFL. These evaluations trigger maintenance decisions.
- The frequency, methods, and quality of rubber removal operations affect both short-term friction restoration and long-term pavement deterioration rates.
- Deterioration rates influence the timing and cost of major rehabilitation works, which in turn determine overall life-cycle cost and funding needs.

By collecting and analyzing real operational data, the study will calibrate and validate this conceptual framework and then propose it as a practical decision-support tool for aerodrome maintenance managers.

9. Methodology

9.1 Research Design

This study will adopt a descriptive and analytical research design. It is **descriptive** in the sense that it will document actual friction performance, rubber removal activities, and maintenance costs over a defined period at a specific aerodrome. It is **analytical** in that it will examine relationships between variables and interpret these relationships in light of the theoretical framework.

The research will be predominantly quantitative, relying on numerical data such as friction measurements, traffic counts, maintenance dates, and cost figures. However, qualitative insights from existing procedures, internal reports, and professional judgment will be used to interpret the data, understand operational constraints, and refine the proposed framework.

No additional field tests will be commissioned specifically for this research; instead, the study will rely entirely on routine operational records that are already collected as part of normal aerodrome practices.

9.2 Data Sources

The study will rely on existing operational and maintenance records. The primary data sources will include:

- 9.2.1. CFME friction test reports with values per 100-metre segment, for each runway end.
- 9.2.2. Flight-traffic statistics include the number of daily or monthly turbojet landings and, where possible, information on aircraft categories or weight classes.
- 9.2.3. Rubber removal records, including dates, methods used, runway sections treated, and any available information on operating settings.
- 9.2.4. Pavement condition information, such as visual inspection reports, condition indices, or qualitative notes describing texture, cracking, or other surface changes.
- 9.2.5. Maintenance and rehabilitation cost data, including direct costs where available and estimated costs based on standard unit rates and engineering benchmarks where records are incomplete.

9.3 Data Collection and Preparation

The researcher will compile the data into a structured database covering the defined study period. For each friction test, associated traffic data and recent maintenance history will be recorded. The aim is to build a chronological picture of how friction varies over time and across runway segments in relation to traffic intensity and maintenance interventions.

Data will be cleaned and checked for consistency. Outliers or unusual measurements will be reviewed and, if necessary, excluded with justification. Missing data will be handled carefully, and any assumptions used for interpolation or estimation will be documented transparently.

Cost data that exist in lump-sum form will be broken down where feasible using unit-rate information and engineering judgment. This will allow meaningful comparison of alternative maintenance strategies at an aggregated level.

9.4 Data Analysis

Data analysis will proceed in several stages:

9.4.1. Descriptive Analysis

9.4.1.1. Summarize friction levels by segment, runway end, and time.

9.4.1.2. Summarize traffic intensity and composition for the same periods.

9.4.1.3. Summarize frequencies and types of rubber removal operations, as well as associated costs.

9.4.2. Relationship and Trend Analysis

9.4.2.1. Examine correlations between traffic variables and friction deterioration rates.

9.4.2.2. Analyze friction trends relative to the timing of rubber removal operations.

9.4.2.3. Explore relationships between removal frequency/method and observed pavement condition changes, where data permit.

9.4.3. Scenario and Comparative Analysis

9.4.3.1. Compare the observed (predominantly reactive) maintenance approach with hypothetical predictive strategies based on trend analysis.

9.4.3.2. Estimate the impact of different strategies on friction reliability, pavement life, and cost over a defined planning horizon.

9.4.4. Framework Development

9.4.4.1. Based on the findings, develop an integrated decision-support framework summarizing key indicators, thresholds, and recommended decision steps.

9.4.4.2. Test the framework conceptually on the existing data to demonstrate how it would have influenced past decisions and outcomes.

9.5 Ethical and Confidentiality Considerations

The study involves operational data that may be sensitive. To protect confidentiality:

9.5.1. The identity of the aerodrome will be anonymized in all reports.

9.5.2. Data will be used purely for academic purposes within the scope of this MBA research.

9.5.3. No operationally sensitive information (such as real-time safety-critical data) will be disclosed.

9.5.4. The research will adhere to the university's ethical guidelines and any specific data-sharing agreements with the aerodrome operator.

10. Expected Results and Contribution

Although the research has not yet been carried out, several expected outcomes can be anticipated:

- The analysis is expected to confirm that flight-traffic intensity and aircraft weight mix have a significant influence on friction deterioration rates, particularly in touchdown zones.
- It is likely to show that more frequent or more aggressive rubber removal operations correlate with accelerated surface deterioration, especially on older or thermally stressed asphalt surfaces.
- The comparison between reactive and predictive maintenance strategies is expected to demonstrate that predictive scheduling based on trends can maintain safety while reducing the total number of interventions over time.
- Cost analysis is expected to indicate that optimized friction and rubber management can reduce life-cycle costs, even if some individual interventions are adjusted in timing or scope compared to traditional practices.

The principal contribution of the study will be a practical, integrated decision-support framework that:

- Links traffic patterns, friction trends, and maintenance activities.
- Incorporates engineering insights on deterioration.
- Embeds financial considerations and life-cycle cost thinking.

In addition, the framework is expected to strengthen the justification of maintenance budget requests by demonstrating how optimized intervention timing reduces unnecessary surface damage, extends rehabilitation cycles, and enhances the efficiency of long-term pavement funding.

This framework is intended to be directly usable by aerodrome maintenance teams and managers to strengthen planning, justify funding, and support safer and more sustainable runway operations.

Overall, the study is expected to illustrate that transitioning from reactive friction management to a predictive, data-driven strategy enables aerodromes to achieve safer operations, improved pavement resilience, and more sustainable use of maintenance funds

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