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Innovative Enhancement of Runway Classification for Improving Airport Capacity Operations: An ICAO Annex 14 - Based Approach

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Abstract

Airport capacity constraints, particularly on runways, have become a critical challenge for global air transport growth. The International Civil Aviation Organization (ICAO) Annex 14 provides standardized runway classification criteria to ensure safety and interoperability; however, these standards may limit operational flexibility at capacity-constrained airports. This research explores innovative enhancements to runway classification within the ICAO Annex 14 framework to improve airport capacity operations without compromising safety. By integrating aircraft performance characteristics, operational demand patterns, and technological advancements, this study proposes an adaptive runway categorization concept aimed at optimizing runway utilization. The findings suggest that a more flexible and performance-based runway classification approach can significantly enhance airport capacity, operational efficiency, and resilience.

Keywords: Runway classification, Airport capacity, ICAO Annex 14, Innovative airport operations, Runway utilization

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Introduction

The rapid growth of air traffic demand has intensified pressure on airport infrastructure, particularly runway systems, which are widely recognized as the primary bottleneck in airport capacity (Ashford et al., 2013). While constructing new runways is often constrained by environmental, land-use, and financial limitations, improving operational efficiency within existing infrastructure has become a strategic priority.

ICAO Annex 14 establishes standardized runway classification systems such as Aerodrome Reference Code (ARC), to ensure global safety and harmonization (ICAO, 2022). Although effective for safety assurance, the rigid application of these classifications may limit operational flexibility and restrict capacity enhancement opportunities. This research investigates how innovative runway category enhancements, aligned with ICAO Annex 14 principles, can improve airport capacity operations without undermining safety objectives.

Literature Review

Airport Capacity and Runway Constraints

Airport capacity is commonly defined as the maximum number of aircraft operations that can be accommodated under given conditions while maintaining acceptable delay levels (Horonjeff et al., 2010). Runways typically represent the most critical constraint due to separation standards, wake turbulence, and runway occupancy time (ROT) (de Neufville & Odoni, 2013).

Previous studies emphasize that capacity improvements can be achieved not only through physical expansion but also through operational and procedural innovations, such as optimized runway usage and aircraft mix management (Doganis, 2019).

ICAO Annex 14 and Runway Classification

ICAO Annex 14 introduces the Aerodrome Reference Code (ARC), which classifies runways based on aircraft reference field length (Code Number) and wingspan or outer main gear wheel

span (Code Letter) (ICAO, 2022). This system ensures that runway geometry, strength, and safety areas are compatible with the intended aircraft types.

However, several scholars argue that ARC application tends to be conservative, often designed for the most demanding aircraft rather than the most frequent users, leading to underutilization of runway capacity (Kazda & Caves, 2015).

Innovative and Performance-Based Approaches

Recent research highlights the potential of performance-based and risk-informed approaches to airport infrastructure management (EUROCONTROL, 2021). These approaches allow operational differentiation based on aircraft performance, weather conditions, and traffic demand, rather than static infrastructure categories alone.

Such innovations align with ICAO's move toward performance-based regulation, suggesting opportunities to enhance runway classification flexibility while maintaining compliance with Annex 14 safety principles.

Objective

This study adopts a qualitative and conceptual research approach. ICAO Annex 1 4 standards are systematically reviewed and analyzed alongside existing literature on airport capacity and runway operations. Best practices and emerging concepts in performance-based airport management are synthesized to develop an innovative runway classification enhancement framework.

The study proposes an Innovative Runway Classification Enhancement Framework grounded in the principles of the International Civil Aviation Organization (ICAO) Annex 1 4, with the objective of improving airport capacity operations through more efficient runway utilization.
Innovative Runway Classification Enhancement Concept

Key findings

Limitations of Conventional Runway Classification

Conventional runway classification typically assumes uniform operational requirements for all aircraft within a given ARC. This approach does not fully account for variations in aircraft performance, actual traffic mix, or time-dependent operational demand.

Proposed Adaptive Runway Categorization

This research proposes an Adaptive Runway Categorization (ARC+) concept, which supplements ICAO Annex 14 classifications with operational layers, including:

1. Aircraft performance profiles (takeoff and landing distance under specific conditions)
2. Traffic demand segmentation (peak vs. off-peak operations)
3. Operational constraints (weather, visibility, and runway occupancy time)

Under this concept, a single runway may support multiple operational sub-categories, enabling more efficient scheduling and allocation of runway use while remaining compliant with Annex 14 dimensional and safety requirements.

Implications for Airport Capacity

By aligning runway usage more closely with actual operational needs, the ARC+ concept can reduce runway occupancy time variability, improve sequencing efficiency, and increase effective runway capacity. This approach also supports collaborative decision-making and advanced surface management systems.

Discussion

The proposed enhancement does not seek to replace ICAO Annex 14 but rather to extend its application through innovative, performance-based operational practices. This aligns with ICAO's safety management philosophy, which emphasizes risk assessment and continuous improvement.

For capacity-constrained airports—particularly those unable to expand physically—the adaptive runway classification concept offers a practical pathway to capacity enhancement, resilience, and sustainability.

Conclusion

This paper demonstrates that innovative enhancement of runway classification, grounded in ICAO Annex 14 principles, can significantly improve airport capacity operations. By integrating aircraft performance, demand variability, and operational context, airports can achieve higher efficiency without compromising safety. Future research should focus on quantitative validation through simulation and case studies at major international airports.

Theoretical Implications

ICAO Annex 14 as the Regulatory Foundation

At the foundation of the framework is ICAO Annex 14 – Aerodromes, which establishes standardized requirements for runway design, classification, and operational safety through the Aerodrome Reference Code (ARC). The ARC system ensures global harmonization and safety by defining runway characteristics based on aircraft reference field length and wingspan or outer main gear wheel span (ICAO, 2022). While this framework is essential for safe aerodrome operations, its application in many airports remains predominantly static.

Conventional Runway Classification Approach

In conventional practice, runway classification is typically designed to accommodate the most demanding aircraft expected to operate at the airport, regardless of traffic frequency or operational context. This static application of ARC may result in conservative operational constraints and suboptimal utilization of runway capacity, particularly at airports with heterogeneous aircraft fleets and variable demand patterns.

Practical Implications

Innovative Runway Classification Enhancement (ARC+)

To address these limitations, this research introduces an Adaptive Runway Categorization (ARC+) concept, which supplements the conventional ICAO Annex 14 classification with additional operational and performance-based variables. These variables include:

- Aircraft performance characteristics, such as actual takeoff and landing distance requirements under specific environmental conditions;
- Traffic demand patterns, distinguishing between peak and off-peak operational periods;
- Runway Occupancy Time (ROT), which directly influences runway throughput and separation efficiency; and
- Operational and environmental conditions, including weather, visibility, and wind components

By integrating these factors, the ARC+ concept enables a more flexible and context-sensitive runway categorization while remaining compliant with ICAO Annex 14 dimensional and safety requirements.

Optimized Runway Utilization and Capacity Outcomes

The implementation of the enhanced runway classification framework leads to optimized runway utilization, characterized by more efficient aircraft sequencing, reduced variability in runway occupancy time, and improved allocation of runway resources. As a result, airports may achieve measurable improvements in operational performance, including increased runway throughput, reduced delays, and enhanced operational resilience.

Contribution to Airport Capacity Operations

Rather than replacing existing ICAO standards, the proposed framework extends the application of Annex 14 through innovative, performance-based operational practices. This approach aligns with ICAO's broader safety management and performance-based regulation philosophy and offers a practical pathway for capacity enhancement at infrastructure-constrained airports. The framework also provides a conceptual foundation for further integration with advanced airport operational systems such as Airport Collaborative Decision Making (A-CDM) and surface movement optimization tools.

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