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# Leveraging AI for Enhanced Runway Safety Management in Airports: Key Implementation Factors

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***Abstract*:**

*Runway safety remains one of the most critical and complex aspects of airport operations, given its direct impact on the safety of passengers, crew, and aircraft, as well as the overall efficiency of airport traffic management. With the increasing complexity and volume of air traffic worldwide, there is a growing imperative to leverage advanced intelligent systems capable of predicting and preventing runway incidents before they occur. This study focuses on investigating the key factors that influence the successful implementation of Artificial Intelligence (AI) integration aimed at enhancing runway safety management. The study employs a qualitative methodology, combining expert interviews, with Delphi technique to gather consensus from a diverse panel of aviation professionals, regulatory authorities, and AI specialists.*

*The research systematically explores multiple dimensions critical to AI integration, including technical readiness, organizational culture, regulatory compliance, and human factors engagement. By synthesizing these insights, the study proposes a comprehensive conceptual framework designed to guide airport authorities, policymakers, and technology providers in effectively integrating AI-driven solutions into existing runway safety protocols. The practical framework emphasizes a balanced approach that aligns technological innovation with operational realities and regulatory requirements. Furthermore, the paper offers actionable recommendations to address the challenges and opportunities identified during the research process, aiming to facilitate smoother transitions toward AI-enhanced runway safety systems.*

*In conclusion, the expert panel demonstrated strong consensus that AI can significantly enhance runway operational efficiency and strengthen runway safety management, underscoring the critical perspective of aviation experts on its strategic value*

***Keywords*: Artificial Intelligence AI, Runway Safety, Aviation Stockholders**

## 1. Introduction

Air travel has become a fundamental pillar of modern transportation, contributing significantly to economic development and global connectivity. With the sharp increase in flight frequency and passengers, ensuring airport runway safety has become more critical than ever. Runway incursions, which involve unauthorized aircraft, vehicles, wildlife or drones on runways, jeopardize aviation safety. Additionally, runway excursions occurring when aircraft overrun or veer off the runway, present significant risks to aviation safety (Public Authority for Civil Aviation, 2020). These challenges have prompted the aviation industry to seek smarter, more responsive safety management systems.

The International Civil Aviation Organization (ICAO), along with national bodies such as the Civil Aviation Authority (CAA), sets the regulatory framework for ensuring safe and efficient airport operations, as outlined in (Aerodromes ICAO annex 14). Within this framework, Runway Safety Teams (RSTs) play a key role in hazard identification, risk assessment, and incident prevention (International Civil Aviation Organization, 2015). However, traditional safety procedures often face limitations in response time and predictive capabilities, especially as air traffic density increases.

Artificial Intelligence (AI) presents a transformative opportunity to enhance runway safety, by enabling real-time monitoring, predictive analytics, and decision support. Despite its potential, the integration of AI technologies into runway safety management remains limited, due to challenges related to regulation, technical readiness, and organizational change.

This study aims to:
(a) Identify the key factors linking AI integration with runway safety management,
(b) Analyze stakeholder consensus on those factors.
(c) Propose practical guidelines to support the integration of AI in this domain.

These guidelines present actionable steps for integrating AI into airport operations. They specifically address the complexities of deployment in safety-critical environments.

## 2. Related Work

Runway safety is a critical component of aviation operations, with reported incursions rising significantly in recent years (Johnson et al., 2016). Traditional mitigation measures—such as ground surveillance radars and Advanced Surface Movement Guidance and Control Systems (A-SMGCS)—have reduced incidents but remain limited in scope (International Civil Aviation Organization, 2004).

Recent research has explored the integration of Artificial Intelligence (AI) into runway operations, leveraging machine learning, computer vision, and sensor fusion. For example, YOLO (You Only Look Once) models have been effectively applied for bird and drone detection to prevent runway hazards (Chen Y., Liu, & Wang, 2023). Convolutional neural networks (CNNs) and deep learning algorithms have been used for real-time intrusion detection, automated vehicle tracking, and FOD (foreign object debris) classification (Chen & Juang, 2019). Sensor fusion techniques that combine visual, infrared, radar, and lidar inputs further enhance monitoring reliability under diverse conditions (Dewitte et al., 2021).

Despite these advances, AI integration in operational runway safety remains slow, hindered by regulatory uncertainty, validation challenges, human-AI interaction issues, high costs, and organizational resistance. Aligning AI systems with international standards (ICAO, FAA, EASA, and national CAA) is critical but underexplored, highlighting a gap between technical capability and practical deployment.

This study addresses these gaps by identifying the key factors linking AI integration with runway safety management, analyzing stakeholder consensus on these factors, and proposing practical guidelines for safe and compliant AI integration. By bridging technical potential and operational implementation, this research extends existing literature and provides actionable insights for airports seeking to enhance safety through AI.

## 3. Methodology

This study adopts a qualitative research approach to explore the key factors influencing AI in runway safety management systems. Given the complexity of aviation operations and the need to capture expert perspectives across multiple disciplines, the Delphi method was employed to facilitate structured expert consensus-building.

A purposive sampling technique was used to recruit a panel of experts from various fields relevant to the study topic, including airport operations, aviation safety, civil aviation regulation, and AI technology experts. Panel members were selected based on their professional experience in aviation safety management, expertise in AI applications, and participation in airport operational decision-making.

The Delphi process involved two rounds of questionnaires administered physically and electronically as in Figure 1. In the first round, experts were asked open-ended questions to identify perceived barriers, enablers, and critical factors influencing AI integration in runway safety systems. Their responses were thematically analyzed to develop a list of factors. In the subsequent round, experts rated and reviewed these factors using a level agreement scale, allowing the study to quantify the level of agreement among participants. Feedback from each round was anonymized and shared with the group, helping to refine and narrow down the factor set.

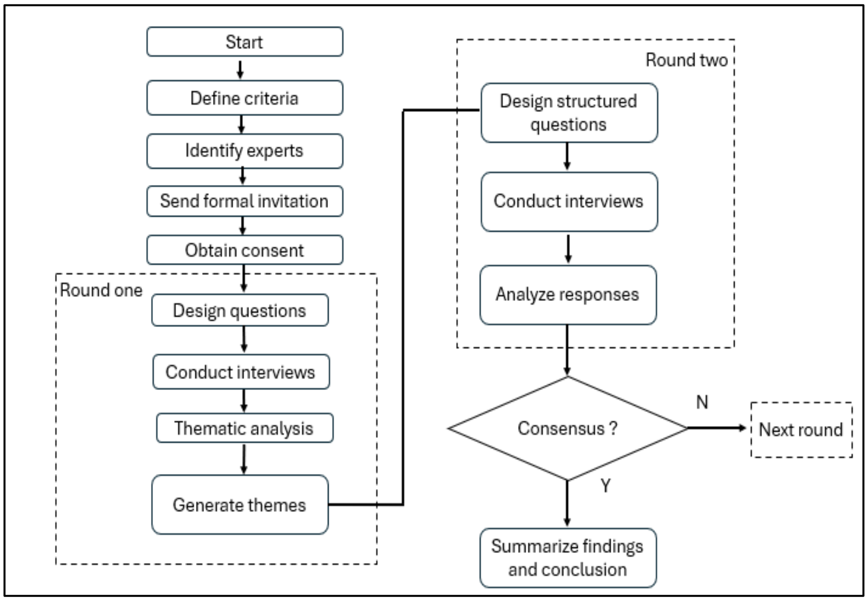


**Figure 1:** Flowchart of Delphi research process

To statistically assess the level of agreement among the expert panel, Kendall's coefficient of concordance (W) was applied (Richard & Koch, 1977). This non-parametric statistic measures the degree of consensus among raters. A higher value of Kendall's W indicates stronger agreement, thereby validating the relevance and prioritization of the identified factors. The interpretation of Kendall's W, commonly used in Delphi studies to assess expert consensus, is presented in Table 1 (Richard & Koch, 1977).

**Table 1**: interpretation of Kendall's W

| Kendall's W | Level of Agreement |
|---|---|
| $0.00 \leq W < 0.20$ | Slight agreement |
| $0.20 \leq W < 0.40$ | Fair agreement |
| $0.40 \leq W < 0.60$ | Moderate agreement |
| $0.60 \leq W < 0.80$ | Substantial agreement |
| $W \geq 0.80$ | Almost perfect agreement |

To ensure domain-relevant insights, a purposive sampling approach was used to select an expert panel consisting of 11 professionals with direct experience in runway safety, aviation operations, civil aviation regulation, and AI aviation systems. The panel included personnel from different aviation agencies in Oman and a university-based AI specialist in aviation technology. Each expert was assigned a unique code (e.g., E001, E002) to maintain anonymity while enabling data tracking. The diversity of roles—ranging from airport safety managers and runway officers to pilots and engineers—ensured a comprehensive evaluation of AI implementation factors. Panel members engaged in a Delphi-based assessment, employing a 5-point Likert scale to evaluate the relevance and potential impact of various AI implementation factors. The scale was defined as follows: (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree).

These quantitative scores were used alongside qualitative analysis, to validate the degree of consensus and prioritize areas, for integrating AI in runway safety management. Meanwhile after the second Delphi round, the process resulted in the identification of 16 validated factors that formed the basis for discussion and analysis. These factors (as in table 2), have achieved acceptable consensus levels (as confirmed by Kendall's W coefficient). Experts identified key factors for integrating AI into runway safety management. The discussion emphasizes consensus-driven factors from the second Delphi round, while the recommendations synthesize insights from both rounds to provide a comprehensive, forward-looking perspective.

### 3.1 Panel Selection and Delphi Process

The Delphi method requires structured planning and systematic analysis to effectively capture expert opinion and build consensus. It is considered an appropriate approach for this study, as it provides a reliable means of eliciting expert judgment on the integration of AI into runway safety management. The method is particularly suited to complex and multidisciplinary topics, where empirical data may be limited, but expert insights can generate robust recommendations.

### 3.2 Expert Selection Criteria

To ensure rigor, panel members were selected according to the following criteria:

(a) Aerodrome Operations Experience:
   i. Professional experience in roles such as air traffic control, airport operations, maintenance, or airport management.
   ii. Awareness of regulatory frameworks, with practical exposure to compliance processes in organizations such as the International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), or the European Union Aviation Safety Agency (EASA).

(b) Knowledge of AI Technology:
   i. Familiarity with recent advancements and practical applications of AI in aviation safety.
   ii. Understanding of aviation safety principles, with a particular focus on integrating AI into runway safety management systems (SMS).

(c) Experience and Credentials:
   i. A minimum of five years of professional experience in aviation safety, regulation, or related technical domains.
   ii. Preferably, academic qualifications at the postgraduate level (e.g., master's or Ph.D.) in fields such as computer science, engineering, or aviation management.
   iii. An international aviation license is advantageous for operational insight but not mandatory, particularly for experts with a technical AI background.

(d) Diversity and Multidisciplinary Representation:
   i. Inclusion of multidisciplinary experts to capture a holistic view of AI implementation in runway safety.
   ii. Geographic diversity represents different regulatory environments, operational practices, and challenges across regions.

(e) Availability, Skills, and Commitment:
   i. Willingness and capacity to commit sufficient time to participate across multiple Delphi rounds.
   ii. Strong communication skills to articulate opinions clearly and contribute constructively.
   iii. A collaborative attitude, reflected in openness to provide feedback, engage in discussions, and work toward consensus.

By applying these criteria, the Delphi panel was composed of highly qualified and diverse experts capable of providing valuable insights into the integration of AI in runway safety. A total of 11 experts were selected, reflecting the limited availability of qualified professionals within a single airport and the broader aviation sector in Oman. Nevertheless, this panel size is consistent with established Delphi methodology, where 10 to 18 participants are recommended to ensure productive group dynamics and consensus (Veugelers et al., 2020; Yoon et al., 2018).

### 3.3 Recruitment and Engagement

Panel members were approached formally through official letters, which outlined the purpose of the study and requested permission to involve relevant employees engaged in runway safety and operational management. After securing approval, an initial meeting was organized to present the study objectives, explain the Delphi process, and invite participants to provide informed consent.

### 3.4 Delphi Round One and Thematic Analysis

In the first Delphi round, the questionnaire was structured into four domains: runway safety control, aviation regulations, runway operational procedures, and AI technology applications. Experts provided feedback across these domains, ensuring that responses captured a broad range of operational, regulatory, and technological perspectives.

Responses were analyzed thematically by coding expert input within each domain. Emerging themes were consolidated to identify areas of consensus and divergence, forming the basis for the design of subsequent Delphi rounds. This systematic approach enhanced transparency and ensured that the analysis remained grounded in the participants' professional expertise.

## 4. Result Discussion

The expert panel identified several critical factors influencing the integration of AI in airport runway safety management systems. The average scores (M) (Table 2) and the consensus analysis using Kendall's coefficient (Figure 2) together provide insights into both the perceived importance of these factors and the degree of agreement among experts. Considering both measures allows for a higher level of confidence in the results, ensuring that the discussion reflects not only stakeholder priorities but also the robustness of expert consensus.

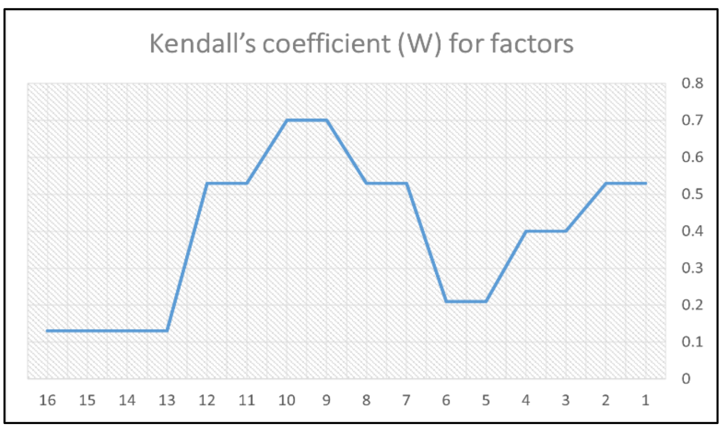


**Figure 2:** The result of expert's response to all factors

### 4.1 High-Rated Factors

Several factors received consistently high ratings, reflecting strong expert agreement on the potential of AI integration in runway safety management. For instance, *AI implementation can improve runway safety* (M = 4.55; W = 0.40) and the *current runway procedures are non-AI technology* (M = 4.54; W = 0.53) indicate a shared recognition that existing systems are largely traditional and that AI offers significant opportunities for enhancement. Similarly, *AI can improve the operational efficiency of runways* (M = 4.27; W = 0.70) demonstrates substantial consensus, highlighting experts' acknowledgment of AI's ability to provide real-time monitoring, predictive insights, and rapid decision support to reduce delays and enhance coordination.

Additionally, *risk management can be enhanced with AI* (M = 4.18; W = 0.53) and *AI can assist in real-time decision-making* (M = 4.18; W = 0.21) further underscore the recognized value of AI in improving operational and safety outcomes. These findings emphasize the importance of prioritizing AI integration in runway safety strategies while addressing associated challenges such as data governance and system compatibility.

**4.2 Low-Rated Factors**

Multiple factors received lower ratings, reflecting variability in awareness, familiarity, and consensus among experts. For instance, *AI currently is in use by other airlines in flights* (M = 3.36; W = 0.13) and *the speed of AI diffusion in the aviation industry is unpredictable due to technical factors* (M = 3.45; W = 0.13) highlight uncertainties regarding adoption timelines and industry readiness. Likewise, *AI has the capability to control and reduce wildlife risk on runways* (M = 3.73; W = 0.13) and *AI has the capacity to be used in maintenance and engineering tasks* (M = 3.81; W = 0.13) scored modestly, likely due to uneven distribution of expertise: engineers may be familiar with predictive maintenance applications, whereas operational managers and pilots may have limited exposure. These results underscore the need for targeted training, awareness programs, and technical support to enhance understanding and adoption of AI across all runway safety functions.

**4.3 Consensus Analysis**

The Kendall's W analysis provides additional insight into expert agreement across the evaluated factors. High consensus was observed for factors such as AI improving operational efficiency of runways and aviation regulation evaluation improved through AI (W ≈ 0.70), indicating a strong alignment in expert views regardless of differences in perceived importance. In contrast, awareness of challenges concerning data integration with AI (W = 0.53) and runway safety management process improvement using AI technology (W = 0.53) exhibited lower consensus, reflecting divergent perspectives on technical feasibility, integration complexity, and implementation readiness. These results suggest that while certain operational applications of AI are widely recognized, uncertainties remain in areas requiring technical integration and organizational adaptation.

**4.4 Integrated Interpretation**

There is strong support and consensus among experts regarding the operational applications of AI, particularly in domains directly linked to safety enhancement, operational efficiency, and real-time decision support. These areas are perceived as offering immediate and tangible benefits, making AI integration both appealing and justifiable.

However, notable knowledge gaps remain in specialized domains. Lower scores in areas such as maintenance, engineering, and the unpredictable speed of AI technology indicate uneven levels of awareness across expert groups. While engineers tend to have a stronger understanding of AI's potential, other stakeholders, including pilots and regulators, appear to have limited exposure to these applications. This uneven familiarity highlights the need for targeted awareness programs and capacity-building initiatives.

Uncertainty also persists regarding integration challenges. Factors that received both low scores and low consensus, particularly those related to data integration, point to unresolved concerns about interoperability with existing systems. These findings emphasize the importance of addressing technical and organizational barriers before large-scale implementation of AI solutions in runway safety management.

Overall, the findings reflect optimism toward AI integration in runway safety, while underscoring the need for regulatory alignment, robust infrastructure, and stakeholder training to bridge knowledge gaps. A pragmatic path forward would involve focusing initial deployment on operational areas with strong expert support, while progressively building confidence and capability in more specialized domains.

**Table 2**: Expert panel average score

| Factor No | Factor | Average Score (M) |
|---|---|---|
| 1 | The current runway procedures are non-AI technology | 4.54 |
| 2 | Unfamiliar with AI applications used in aviation safety | 3.73 |
| 3 | The runway safety areas to be enhanced through AI technology can be specified clearly | 4.00 |
| 4 | AI implementation can improve runway safety | 4.55 |
| 5 | AI can assist in real-time decision-making | 4.18 |
| 6 | Improvement is required to support AI integration with current data system | 3.64 |
| 7 | Risk management can be enhanced with AI | 4.18 |
| 8 | Awareness of the challenges concerning data integration with AI needs addressing and advance planning | 3.36 |
| 9 | AI improve operational efficiency of runway | 4.27 |
| 10 | AI can assist in aviation regulation compliance | 3.36 |
| 11 | Aviation regulation evaluation improved through AI | 3.36 |
| 12 | Runway safety management process can be improved using AI technology | 4.00 |
| 13 | The speed of AI diffusion in aviation industry is unpredictable due to many technical factors | 3.45 |
| 14 | AI has the capability to control and reduce wildlife risk in runway | 3.73 |
| 15 | AI has the capacity to be used in maintenance and engineering tasks | 3.81 |
| 16 | AI currently is in use by other Airlines in flights | 3.36 |

### 4.5 Insights And Policy Considerations

The findings of this study highlight a cautiously optimistic outlook for AI integration in runway safety management. The expert panel expressed strong support for operational applications such as real-time decision-assistance, efficiency enhancement, and risk management. By contrast, lower scores for regulatory compliance, data integration, and maintenance applications reveal persistent knowledge gaps and uncertainties. These patterns become clearer when interpreted through established frameworks of technology adoption and aviation governance.

From an adoption perspective, both the Technology-Organization-Environment (TOE) model and Diffusion of Innovation (DoI) theory emphasize that successful implementation requires not only technological readiness, but also organizational alignment and regulatory support. High ratings for efficiency and risk management suggest perceived readiness, as predictive analytics and monitoring tools are already proven in other transport domains.

However, weaker consensus on data integration and regulatory compliance reflects challenges in the organizational and environmental dimensions, where legacy systems, fragmented architectures, and evolving legal standards remain significant barriers.

Human factors also emerged as a decisive element. Uneven awareness among experts illustrates the socio-technical complexity of adoption. Meanwhile without adequate exposure, key personnel may remain skeptical of AI systems, delaying adoption even in technically viable areas. Addressing this requires targeted training, active stakeholder engagement, and demonstration projects to build cross-group confidence.

The analysis also resonate with international regulatory debates. ICAO has highlighted the importance of predictive, data-driven safety management, which aligns with AI's potential in risk analysis. Similarly, the FAA and EASA have initiated guidance on digitalization and AI, though comprehensive, binding standards are still emerging. The lower expert scores for regulatory compliance likely reflect this evolving landscape, where AI is not yet explicitly codified in ICAO Annex 19 (Safety Management). Clearer international guidance and certification pathways would provide confidence and accelerate adoption.

In summary, the results suggest that AI integration in runway safety must be approached as more than a technical upgrade. It is equally an organizational, cultural, and regulatory challenge. A pragmatic path forward involves leveraging AI first in high-consensus operational domains, while in parallel addressing human factors and policy alignment to enable sustainable and system-wide adoption.

## 5 Conclusion

This study investigated the factors influencing the integration of Artificial Intelligence in airport runway safety management. Using the Delphi method, supported by Kendall's Coefficient of Concordance (W) and average scoring, the study identified both areas of strong consensus and domains of uncertainty. Experts demonstrated substantial agreement on the potential of AI to enhance operational efficiency, support real-time decision-making assistance, and strengthen risk management processes. These operational domains emerged as the most promising entry points for AI integration, reflecting both technological readiness and alignment with aviation safety priorities.

At the same time, the study highlighted uneven awareness across specialized domains. For example, engineers were more familiar with AI applications in predictive maintenance, while pilots and regulators showed limited knowledge of such tools. Similarly, factors related to regulatory compliance and data integration scored lower, reflecting concerns about interoperability with legacy systems and uncertainty in international guidance. These knowledge and policy gaps signal the need for coordinated strategies that go beyond technical solutions to include training, governance, and regulatory adaptation.

Collectively, these findings indicate a cautiously optimistic outlook for AI integration in runway safety management, with strong potential in targeted, high-consensus applications. Broader adoption, however, will depend on addressing human factors, strengthening data infrastructure, and aligning with evolving international regulations (ICAO, FAA, EASA).

## 6 Recommendations

Derived from these findings, this study proposes the following recommendations to support effective and responsible AI integration in runway safety management:

(a) Conduct AI readiness assessments to evaluate current infrastructure, data architecture, and workforce preparedness before large-scale deployment.
(b) Ensure regulatory alignment by engaging closely with ICAO, FAA, EASA, and other bodies to integrate AI applications within existing safety management standards.
(c) Enhance data management capabilities through investment in data quality, interoperability, and cybersecurity to address barriers to integration.

(d) Strengthen awareness and training by developing tailored programs that build competence and trust among pilots, regulators, engineers, and other stakeholders.
(e) Develop human-AI interaction protocols that clearly define roles, minimize human error, and ensure effective operator–AI collaboration.
(f) Implement change management strategies to address resistance and foster a culture of innovation readiness within organizations.
(g) Adopt pilot-driven, scalable approaches by starting with controlled projects in defined areas (e.g., wildlife monitoring, incursion detection) and expanding based on lessons learned.

By grounding these recommendations in the study's findings, this conclusion offers evidence-based guidance for airports, regulators, and safety stakeholders to integrate AI while ensuring compliance, addressing human factors, and upholding global aviation safety standards.

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