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Analysis and Optimization of Flight Operations Data Using of Artificial Intelligence (AI) To Improve Aviation Safety

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Abstract

Introduction: In the aviation industry, safety is a key concern, given the increase in traffic, the growing complexity of systems, and the diversity of risks. Traditional methods of risk management and analysis are now reaching their limits, particularly in light of the vast amount of data to be processed and the need for greater responsiveness. Artificial intelligence is therefore emerging as an innovative solution, capable of analysing, detecting, and predicting risky situations using advanced machine learning algorithms.
The objective: This paper presents the development of a web application called the "Aviation Safety Assistant," designed to automate the analysis of safety data and automatically propose and generate customized mitigation measures-reactive, proactive, and predictive—targeting the sector's three essential lines of defense: training, regulation, and technology.
Methods: The modular technical architecture enables efficient data processing, ensures data confidentiality, and supports local archiving of analyses, PDF report generation, trend analysis, and similarity searches within the database...
Results: The results demonstrate the significant contribution of AI to the optimization of aviation security processes: improved risk detection, time savings for users, standardization of recommendations, and better utilization of feedback.
Conclusion: This study highlights the potential of smart technologies to help industry stakeholders prevent incidents and continuously improve safety, while laying the groundwork for future developments that incorporate even more personalized and predictive solutions.

Keywords: Aviation safety, artificial intelligence, risk analysis, data analysis, mitigation measures.

Introduction

Aviation safety remains a fundamental and ongoing challenge for the airline industry and regulatory authorities [1]. Against a backdrop of sustained traffic growth, increasingly complex technologies, and a variety of risks, the need for reliability and responsiveness is greater than ever [2, 3]. Air operations today generate a considerable volume of data, making the management of risk situations increasingly challenging [4]. Faced with this growing complexity, traditional methods of risk analysis and management are reaching their limits, particularly when it comes to anticipating multiple and unprecedented scenarios [5,6].

It is in this context that artificial intelligence (AI) has emerged as an innovative and indispensable solution [7,8]. Thanks to its ability to process vast datasets, detect patterns invisible to the human eye, and generate real-time recommendations [11], AI is revolutionizing aviation safety practices [9-10]. It offers the possibility of shifting from reactive to proactive management, thereby optimizing prevention and decision-making in critical environments [12].

This project aligns with the current trend toward innovation and digital transformation. It focuses on integrating AI into the analysis and optimization of flight safety data through the design and development of an interactive web application: "Aviation Safety Assistant." This platform offers a new approach to risk management, leveraging advanced methods of natural language processing and machine learning. Users can report an adverse event, obtain an automated risk analysis, and receive personalized mitigation measures.

The structure of our work follows a rigorous approach: after examining the fundamentals and challenges of aviation safety, we focus on AI concepts and methods, as well as their practical applications in the sector. [13] The core of the work details the design, technical choices, application architecture, and integrated AI algorithms, before offering a critical evaluation of the solution and its prospects for further development.

This study thus aims to demonstrate how artificial intelligence can effectively optimize risk management in aviation and contribute to a safer, smarter, and more resilient aviation industry, one that is adapted to the sector's new challenges. [14].

In this context, a key question arises: How can we practically leverage recent advances in artificial intelligence to design a tool capable of automatically analysing aviation safety data and proposing relevant,

customized mitigation measures tailored to each situation? In other words, how can we transition from reactive, manual incident management to proactive, intelligent, and automated management, while ensuring the reliability of analyses, regulatory compliance, and the business acceptability of the proposed solutions?

STUDY OF AVIATION SAFETY:

1. Introduction to Aviation Safety

Safety is at the heart of aviation. Every flight, every procedure, and every decision is driven by the need to protect lives. Through strict regulations, cutting-edge technology, and ongoing training, the industry works tirelessly to minimize risks and ensure that air travel remains one of the safest modes of transportation.

1.1 Safety-Related Concepts

Accident: An event related to the operation of an aircraft that, in the case of a manned aircraft, occurs between the time a person boards with the intention of flying and the time all such persons have disembarked, or, in the case of an unmanned aircraft, between the time the aircraft is ready to maneuver for flight and the time it comes to a stop at the end of the flight and its main propulsion system is shut down, and during which:

(a) A person is fatally or seriously injured as a result of being:

- On board the aircraft,
- In direct contact with a part of the aircraft, including detached parts,
- Directly exposed to jet blast, except in the case of injuries resulting from natural causes, self-inflicted injuries, injuries inflicted by a third party, or injuries sustained by a stowaway hidden outside areas accessible to passengers and crew; or
- The aircraft sustains structural damage or failure:
- That impairs its strength, performance, or flight characteristics,
- That would normally require major repair or replacement of the damaged component,

Except in the event of an engine failure or damage, when the damage is limited to a single engine (including its cowlings or accessories), propellers, wingtips, antennas, sensors, angle-of-attack vanes, tires, brakes, wheels, fairings, panels, landing gear doors, windshields, fuselage skin (such as small perforations), or minor damage to main rotor blades, tail rotor blades, or damage caused by hail or bird strikes (including perforations in the radome); or

(b) The aircraft is missing or completely inaccessible.

Incident: An event, other than an accident, related to the operation of an aircraft that compromises or could compromise operational safety.

Safety data: A defined set of safety facts or values collected from various aviation-related sources, which is used to maintain or improve safety.

Hazard: A situation or object that could cause or contribute to an aviation incident or accident.

Safety risk: The anticipated probability and severity of the consequences or outcomes of a hazard.

Safety information: Safety data that has been processed, organized, or analyzed in a given context so as to be useful for safety management.

Safety performance indicator: A data-based parameter used to monitor and evaluate safety performance.

1.2 What is safety:

Zero accidents (or serious incidents)? The total absence of danger or risk?

Avoiding errors? Regulatory compliance?

Safety is the state in which the risks associated with aviation activities whether involving aircraft operations or their direct support are reduced and controlled to an acceptable level.

The safety of a system is based on the acceptance of a controlled level of risk and is understood as a systemic property that can only be assessed at the level of the entire system. To ensure this safety, controls must be applied at all levels. The Safety Management System provides the structured framework necessary for this implementation.

1.3 The Importance of Aviation Safety

Aviation safety is a fundamental pillar of the air transport industry, ensuring the safe movement of millions of passengers and tons of cargo around the world. The rapid growth of air travel has made it essential to adopt strict safety regulations and to make continuous progress in risk mitigation strategies. The complexity of modern air travel requires a robust framework of regulations, technological advancements, and operational oversight to minimize risks and improve safety performance.

Safety management systems have become essential for identifying, analyzing, and mitigating potential hazards before they escalate into incidents. According to the FAA, the integration of artificial intelligence into air traffic control, along with the modernization of safety reporting mechanisms, are crucial steps toward reducing operational risks and improving situational awareness.

Regulatory agencies, such as the FAA and ICAO, continually update safety standards to address emerging risks and technological innovations. In addition, industry-wide safety audits, such as the IATA Operational Safety Audit (IOSA), help ensure compliance with international safety standards and contribute to maintaining a strong safety culture within airlines and service providers.

The continuous improvement of safety measures plays a crucial role in reducing the likelihood of accidents. By prioritizing safety at all levels of operation, the aviation industry not only protects human lives but also strengthens public confidence in air travel, thereby reinforcing its role as one of the safest modes of transportation.

1.4 Key Stakeholders in Aviation Safety

Aviation safety is a shared responsibility that requires multiple stakeholders to work together to ensure the highest standards of operational safety.

International Civil Aviation Organization (ICAO): ICAO is a specialized agency of the United Nations that establishes global aviation safety standards through its annexes. It provides guidelines for safety management systems (SMS) and state safety programs, ensuring a standardized approach to aviation safety.

a) Federal Aviation Administration (FAA): The FAA is the national aviation authority of the United States, responsible for regulating and overseeing all aspects of civil aviation in the country. It establishes safety regulations, certifies aircraft and personnel, and enforces compliance through inspections and audits.

b) European Union Aviation Safety Agency (EASA): EASA is the aviation safety regulatory body for the European Union. It harmonizes safety standards among EU member states, oversees aircraft certification, and ensures that airlines meet strict safety requirements.

c) Airlines: They play a crucial role in implementing safety procedures in their operations. They are responsible for aircraft maintenance, crew training, compliance with regulatory requirements, and establishing internal safety management systems to mitigate operational risks.

d) Aircraft manufacturers: Companies such as Boeing and Airbus design and produce aircraft that comply with the strict safety regulations established by ICAO, the FAA, and EASA. Manufacturers conduct rigorous testing and ongoing monitoring to improve aircraft reliability and introduce new safety technologies.

e) **Air Navigation Service Providers:** ANSPs (air navigation service providers), such as the FAA's Air Traffic Organization (ATO) and EUROCONTROL, manage air traffic to ensure safe and efficient operations. They provide real-time surveillance, air traffic control services, and navigation aids to prevent collisions and maintain orderly operations in airspace.

f) Airport Authorities: Airport operators are responsible for implementing ground safety measures, including runway maintenance, emergency response planning, and security screening. They work in collaboration with regulatory agencies and airlines to ensure a safe environment for air travel.

g) Accident investigation agencies: Independent agencies such as the National Transportation Safety Board (NTSB) in the United States and the Bureau of Investigation and Analysis (BEA) in France conduct thorough investigations into aviation incidents and accidents. Their findings have led to safety recommendations aimed at preventing future incidents.

Method

2.1 Challenges in Defining AI:

There is no single, universally accepted definition of AI. Some definitions focus on a machine's ability to mimic human intelligence, while others describe AI based on specific technologies such as machine learning and neural networks. A legal definition of AI must meet several important criteria:

- **Inclusivity**: It should cover AI systems that need to be regulated, while excluding those that do not pose significant risks.
- **Precision**: The definition must clearly specify whether a system can be classified as AI under the law.
- **Comprehensiveness**: It should be easy to understand for legal professionals and non-experts alike.
- **Feasibility:** The definition should be simple enough for courts and regulatory agencies to apply it consistently.
- **Permanence:** It must remain relevant even as AI technology evolves, in order to avoid frequent legal changes. [15]

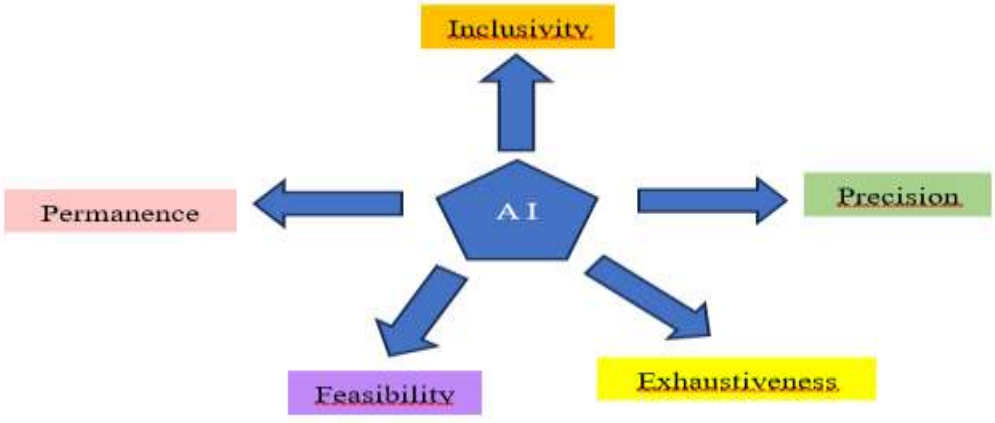


Figure 1. Criteria for a legal definition of AI

3. The Application of AI in Flight Operations

3.1 Air Traffic Optimisation

- Real-time traffic management: Artificial intelligence processes aircraft traffic to optimize routes, reduce delays, and prevent potential collisions, particularly in airspace with very low traffic volumes. [16]
- Congestion prediction: By analysing historical and real-time data (weather, air traffic, incidents), AI can predict periods of congestion and suggest alternative solutions (detours, flight plan changes). [16]

3.2 Assistance au pilotage

- Decision support systems: AI provides real-time recommendations to pilots in the event of adverse weather conditions, technical malfunctions, or emergencies to improve responsiveness and safety. [17]
- Smart autopilots: These systems, which are more advanced than traditional autopilots, can navigate new and complex situations by taking into account a wide range of parameters. [17]

3.3 In-flight Monitoring and Safety

- Anomaly detection: AI continuously monitors flight parameters to detect deviations or abnormal behavior (altitude, speed, flight path), and immediately alerts the crew or ground control. [18]
- Incident prevention: By analyzing thousands of flights, AI identifies patterns that lead to incidents and enables preventive measures to be taken at an earlier stage. [18]

3.4Gestion des communications

- Automatic analysis: AI can analyse radio communications between pilots and air traffic controllers to detect misunderstandings, transmission errors, or garbled signals during training exercises. [19]
- Translation and language support: AI-powered translation provides real-time translation assistance or helps clarify communication, facilitating international operations. [19]

3.5Flight Planning and Preparation

- Flight plan optimization: The AI generates optimized flight plans based on weather conditions, traffic, restricted areas, and aircraft performance, to maximize safety, time efficiency, and fuel efficiency. [17]
- Dynamic update: In the event of an unexpected change (airspace closure, weather), the flight plan can be updated by the AI in real time. [17]

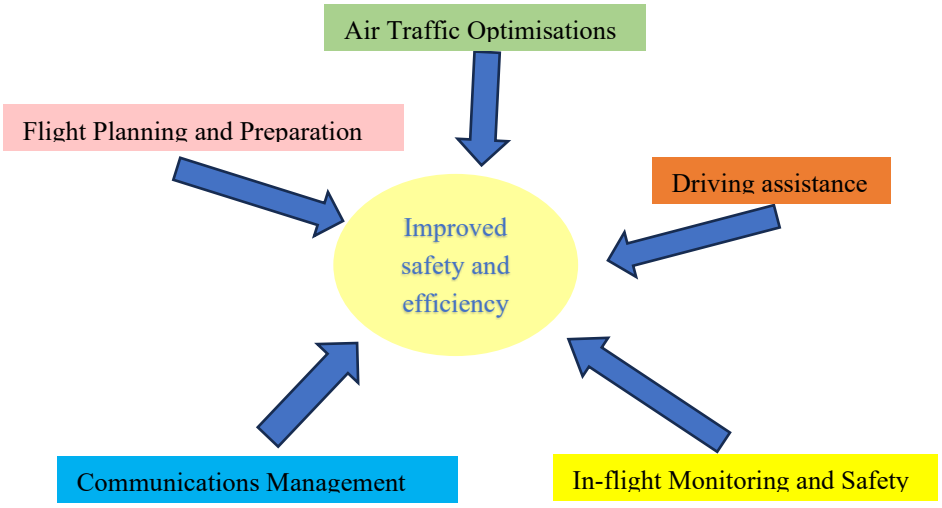


Figure 2. Improving Aviation Safety Through AI

RESULTATS ET DISCUSSION

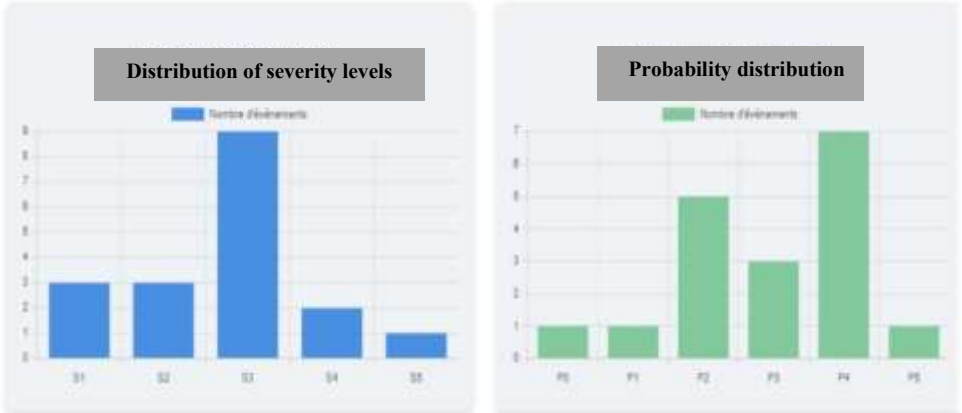


Figure 3. Histograms of distributions (severity/probability

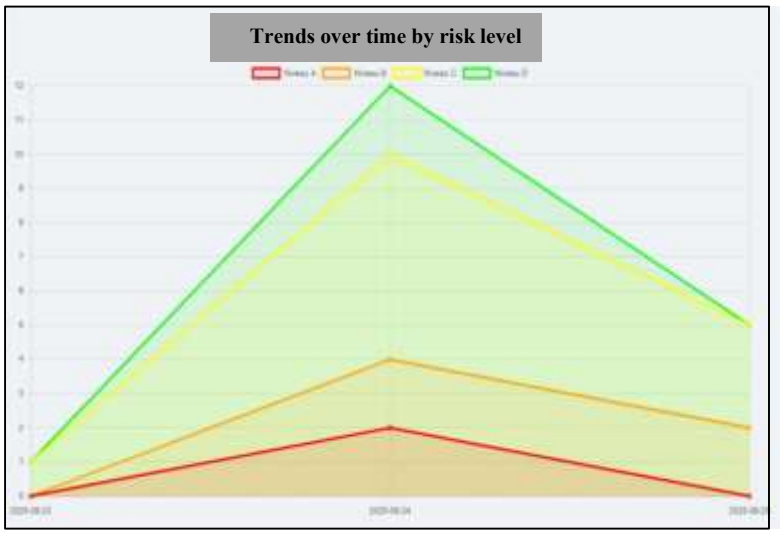


Figure 4. Trends over time by risk level

Conclusion

By the end of this article, it is clear that artificial intelligence is emerging as a key tool for addressing the growing challenges of aviation safety. A thorough examination of the regulatory landscape, operational challenges, and the limitations of traditional methods has shown that digitalization and automation have become indispensable in the face of the ever-increasing complexity and volume of data in this sector.

The integration of AI, particularly through natural language processing and machine learning, has marked a decisive step forward in the proactive management of aviation safety. The development and implementation of a dedicated web platform, the "Aviation Safety Assistant," has brought this innovative approach to fruition. Thanks to this intelligent solution, it has been possible to automate the collection, classification, and analysis of adverse events, detect emerging trends and risks more quickly, and generate tailored and personalized recommendations for risk prevention and mitigation. The platform also offers dynamic data visualization, optimized archiving, and enhanced traceability, all while complying with regulatory and organizational requirements.

More broadly, this work has highlighted the major benefits of AI: the speed and reliability of data processing, the relevance of analyses, the simplification of decision-making for security managers, and the reduction of the workload associated with repetitive tasks. People remain at the heart of the system, but they are now supported by powerful and innovative tools, fostering a safety culture based on continuous learning and collaboration.

The results obtained throughout this study fully confirm the initial hypothesis: artificial intelligence significantly improves the analysis and management of aviation safety data. It overcomes the limitations of traditional manual approaches and provides real added value to risk prevention and management, while ensuring compliance with industry requirements.

Ultimately, this study demonstrates that artificial intelligence, combined with a systematic approach to risk management and a high-performance digital platform, represents a major advance for modern aviation safety. It lays the groundwork for continuous improvement, where technology-working in the service of people—enables us to achieve ever-higher levels of safety that are tailored to the current and future challenges of air transport.

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