

Artificial Intelligence Integration in Air Traffic Management: A Qualitative Content Analysis of the SESAR Research

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Abstract

The aim of the study is to explore the use and integration of Artificial Intelligence (AI) and Machine Learning (ML) technologies within the SESAR projects. Using a qualitative content analysis approach, this research systematically reviewed 232 SESAR project documents and identified 37 projects that directly applied AI/ML models and techniques. These selected projects were further examined to categorize their focus into four key areas: situational awareness and human-AI teaming; trajectory prediction, traffic flow management, and network optimization; automation in communication, navigation, surveillance (CNS), and safety monitoring; and AI integration and ethical governance. The study contributes to the literature by offering a structured framework that highlights the current applications of AI/ML in air traffic management innovation, while also identifying emerging trends and potential future research directions.

Keywords: air traffic management, artificial intelligence, aviation, machine learning, SESAR

1 Introduction

Artificial Intelligence (AI) possesses transformative potential across industries by introducing novel opportunities for innovation and challenging existing operational paradigms [1]. Beyond its sectoral impact, AI also plays a critical role in enhancing technological innovation capabilities within strategic emerging industries by reducing funding constraints and stimulating research and development investments [2]. Current market trends indicate exponential global growth in the AI sector. In 2024, the market size was valued at USD 239.41 billion, and it is projected to expand to USD 328.47 billion in 2025, ultimately reaching USD 4124.10 billion by 2033. This trajectory corresponds to a compound annual growth rate (CAGR) of 37.20% over the 2025–2033 period. The regional expansion of the global AI market exhibits considerable variation across continents, with the Asia-Pacific region emerging as the dominant actor, supported by a projected growth rate of 49.3%, primarily driven by AI applications in the finance and security sectors in countries such as China and India. North America followed with a growth rate of 33.2%, underpinned by advancements in biometric technologies, voice recognition, and autonomous systems. In parallel, Europe has demonstrated notable progress, particularly through the adoption of virtual assistants and biometric security applications, with countries like Germany and the United Kingdom leading such initiatives. Türkiye has also increased its AI investments in unmanned aerial vehicles systems to enhance security. In Latin America, Brazil has incorporated AI technologies to improve public safety, while in the Middle East and Africa, AI adoption is concentrated in asset management and surveillance, frequently supported by partnerships with Chinese technology companies [3].

Among the various industries impacted by AI, the aviation sector stands out as a key area where these technologies are rapidly reshaping operations and addressing longstanding challenges. With its multifaceted operational demands, aviation presents unique opportunities for AI-driven solutions aimed at enhancing efficiency, sustainability, and safety. The sector faces critical issues such as rising fuel prices, environmental pressures, growing customer expectations, and the demand for autonomous systems to improve production efficiency and reduce costs [4]. In response, AI technologies such as machine learning (ML), predictive analytics, robotics, big data analytics, natural language processing (NLP), and computer vision are being widely implemented across various aviation functions, from flight planning and operations to maintenance and safety management [5]. By enabling real-time analysis and automation, these tools enhance decision-making, mitigate operational risks, and boost customer satisfaction [6].

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According to the Straits [7] report, the global AI market in aviation was valued at USD 1015.87 million in 2024 and is expected to reach USD 1493.02 million in 2025. The market is projected to grow at a compound annual growth rate (CAGR) of 46.97% between 2025 and 2033, reaching USD 32500.82 million by 2033. This growth is mainly driven by software-based AI solutions. ML is the leading technology, while virtual assistants are the most common applications. North America holds the largest market share (45.36%), with the U.S. and Canada leading due to their investments in cloud-based software and big data. Airlines are increasingly adopting AI for predictive maintenance, virtual assistants, and monitoring systems to improve operational efficiency. The Asia-Pacific region is the fastest-growing market with a 51.13% CAGR, driven by countries such as China, Japan, and South Korea. The use of ML and natural language processing in training and virtual assistant applications is growing rapidly. The major companies in this market include Amazon Web Services, IBM, Microsoft, NVIDIA, Airbus, Boeing, Lockheed Martin, and Thales [7].

AI has become increasingly integrated into various domains of the aviation sector, including aircraft design and operation, production and maintenance, environmental management, air traffic management (ATM), airport operations, unmanned aerial systems, cybersecurity, and safety risk management [8]. In aircraft design and operations, AI contributes to the optimization of performance [9] through advanced simulations and data-driven decision-making. In production and maintenance, it enables predictive maintenance [10] and automates control [11], thereby reducing downtime and improving safety. AI also supports environmental sustainability by enhancing fuel optimization and reducing emissions [12]. At airports, AI improves operational efficiency through smart systems such as automated baggage handling [13] and passenger flow management [14]. Furthermore, AI plays a critical role in enabling autonomous operations and traffic coordination for drones and urban air mobility solutions [15]. In cybersecurity, AI detects anomalies and prevents potential threats [16], while in safety management, it assists in proactive risk assessment and incident prediction [17]. Among these areas, ATM is particularly significant. ATM offers strong potential for increased automation supported by AI. Due to the repetitive nature of many procedures, aviation and ATM produce large volumes of data that can be used to apply AI tools and advanced automation. These technologies can help improve operational efficiency and enable human operators to concentrate more on tasks that are critical for safety.

ATM is defined as the dynamic and integrated coordination of air traffic and airspace, encompassing air traffic services, airspace organization, and flow regulation to ensure safety, efficiency, and economic performance [18]. Its core function is to address the imbalance between service demand and system capacity, enabling the safe and orderly movement of aircraft across controlled airspace [19]. However, ATM faces several challenges, such as increasing airspace capacity, maintaining high levels of safety, enhancing operational efficiency, reducing fuel consumption and emissions, and minimizing the impact of noise. These challenges require innovative approaches and the integration of advanced technologies. As the aviation industry continues to evolve, ATM is expected to undergo significant transformation in the coming decades [20]. ATM is recognized as a critical domain for technological advancement [21]. Developing intelligent ATM systems that incorporate digitalization, automation, and stakeholder collaboration is essential for achieving safe, efficient, and reliable air traffic operations. The increasing complexity and density of global air traffic demand more efficient and intelligent ATM systems. AI technologies enhance trajectory prediction [22], conflict detection [23], and decision-making [24], thereby reducing the controller workload and improving the situational awareness. These advancements contribute not only to operational efficiency but also to environmental goals by minimizing delays and optimizing fuel consumption. As such, AI is a key enabler in the modernization of ATM systems, aligned with international initiatives like the Single European Sky ATM Research (SESAR).

SESAR constitutes the technological cornerstone of the European Commission's broader Single European Sky (SES) initiative, which aims to enhance the efficiency, capacity, and sustainability of ATM across Europe. In response to the increasing complexity of air traffic and the escalating delays observed during the early 2000s, SESAR was launched as a coordinated European effort to modernize the ATM infrastructure through innovation and system-wide integration. Prior to its establishment, ATM-related research and development activities within the European Union were largely fragmented, conducted independently at national or institutional levels, often lacking strategic alignment or shared implementation pathways. This disjointed landscape limited the scalability of research outcomes and hindered the development of harmonized solutions capable of addressing network-wide performance challenges. Recognizing the urgent need for a unified approach, the SESAR was formally initiated in 2008 under the framework of Regulation (EC) No. 219/2008 of the European Council. Its primary objective was to consolidate and streamline ATM research and development efforts, advancing promising concepts from early-stage research to deployment-ready technologies. Importantly, SESAR sought to reduce redundancy in research activities, foster collaboration among stakeholders, and ensure that innovations contributed to the overall performance of the European ATM network, rather than delivering isolated or locally optimized outcomes. By aligning technological development with strategic policy goals, SESAR plays a central role in shaping a cohesive vision for the

future of the European ATM, emphasizing interoperability, scalability, and environmental sustainability [25].

As the aviation sector increasingly embraces digital transformation, understanding how AI and ML technologies are operationalized within strategic initiatives like SESAR becomes critically important. Despite the growing interest in AI applications in ATM, there remains a lack of comprehensive studies that systematically map how these technologies are being integrated into SESAR-funded innovation efforts. The study addresses this gap by offering an in-depth qualitative analysis of the SESAR project documentation to identify concrete use cases and thematic concentrations of AI/ML implementation. By doing so, the research provides valuable insights into how Europe is leveraging intelligent systems to modernize ATM infrastructure, enhance safety, and support sustainability goals. The findings contribute to the scholarly discourse by presenting an evidence-based framework that not only captures the current landscape of AI/ML adoption in SESAR projects but also informs policymakers, researchers, and practitioners about future opportunities and challenges at the intersection of emerging technologies and air traffic governance.

2 Material and Methods

To analyze the SESAR projects, a qualitative content analysis was conducted. The method enables the systematic interpretation of textual data by identifying recurring patterns and underlying meanings. It involves subjective yet structured coding processes [26], context-sensitive and rule-guided analysis [27], and efforts to reduce and make sense of large volumes of qualitative material [28].

2.1 Purpose and Importance of the Research

The primary purpose of this research is to systematically examine the use and the integration of AI and ML technologies within SESAR projects, aiming to identify key application areas and trends. Given the growing significance of AI/ML in ATM and the broader aviation industry, understanding how these technologies are currently used is critical for guiding future innovations and strategic developments. The study contributes to the literature by providing a comprehensive analysis of AI/ML implementation in SESAR initiatives, thereby offering valuable insights for researchers, policymakers, and industry stakeholders.

2.2 Scope of the Research

The study focuses specifically on projects within the SESAR (Single European Sky ATM Research) portfolio that involve AI and ML technologies. The scope is limited to projects accessible through the SESAR Project Portal, with particular emphasis on those actively developing or employing AI/ML models. Projects unrelated to AI/ML or those without sufficient publicly available data were excluded as well as those that were not considered directly related to ATM. Consequently, the research provides an in-depth exploration of 37 relevant SESAR projects, ensuring a targeted and manageable dataset for detailed content analysis.

2.3 Research Data Collection Process

Data for the study were collected through a systematic review of online resources related to SESAR projects, accessed via the official SESAR Project Portal [29]. The portal provides an overview of ongoing research from the Digital European Sky programme (2021–2028) and completed SESAR 2020 projects (2017–2023). Initially, 232 projects were identified using keyword-based searches focusing on “Artificial Intelligence (AI)” and “Machine Learning (ML)”. To ensure relevance to the field of ATM, projects not directly related to ATM domains were excluded.

From the refined pool, 37 projects were selected based on three transparent inclusion criteria: (1) the presence of clearly defined AI/ML methodologies or applications; (2) a direct focus on ATM operational areas; and (3) the availability of sufficient publicly accessible documentation for qualitative analysis. Project materials—including titles, objectives, and deliverables—were thoroughly reviewed and served as the primary data sources.

To support the validity of the study, these inclusion criteria were applied consistently throughout the selection process. To ensure reliability, a second researcher independently reviewed the selected projects using the same criteria. Minor discrepancies were discussed and resolved through mutual agreement, strengthening the consistency and robustness of the overall analysis.

2.4 Analysis of the Research Data

The collected data were analyzed using qualitative content analysis, a method well-suited for identifying patterns and themes within textual information. The analysis involved the systematic coding of project documents to categorize and classify AI/ML applications across the selected projects. Through iterative

coding cycles, four primary thematic areas were identified. To enhance the validity and reliability of the coding process, expert consultations were conducted with two subject-matter specialists who reviewed the coding framework and offered feedback for refinement. This rigorous approach ensured that the findings accurately reflect the current landscape of AI/ML integration in SESAR projects.

3 Results and Discussion

3.1 Situational Awareness and Human-AI Teaming

The concept of situational awareness, which comes from the field of human factors and is widely used in human-automation systems, refers to the perception of elements in the environment, the understanding of their meaning, and the prediction of their future state [30], [31]. This model includes three main stages: perception, comprehension, and projection. It explains the type of information that humans need to perform well in fast-changing and high-risk environments such as air traffic control [32]. In human-machine systems, situational awareness also includes machine-based assessment, user awareness, and shared understanding between humans and machines [33]. As AI systems are used more often in the workplace, maintaining situational awareness becomes more important for successful cooperation between humans and AI [34], [35]. In this context, explainable AI helps by allowing systems to explain their decisions, show their strengths and weaknesses, and describe how they will act in the future [36]. Considering human factors, elements such as mental workload [37] and stress [38] significantly affect situational awareness and the potential for human error in complex environments like ATM. These factors must be accounted for to optimize the human-AI interaction and ensure safety. Human-AI teaming is a human-centered way of using AI in work settings where AI systems work as team members. These systems use their abilities in learning, problem-solving, and decision-making to support human work [39], [40], [41]. This teamwork model emphasizes addressing key challenges such as trust, transparency, explainability, clear communication, and user-centered design to ensure effective human-AI collaboration [35], [42]. When explainable AI is used in human-AI teams, it can improve shared situational awareness, help with better decision-making, and support the growth of individual skills. It also helps people stay motivated and productive [43], [44], [45]. Therefore, bringing together situational awareness, human factors, and human-AI teaming shows the need for smart, clear, and supportive AI systems in complex work environments.

Building on theoretical foundations such as situational awareness, explainable AI, and human-AI teaming, multiple SESAR-funded projects have aimed to develop practical AI-driven solutions to enhance human-machine interaction in ATM, as shown in Table 1. These projects include 11 exploratory research initiatives, with six completed and five still ongoing. They were launched as early as April 2016 and had a total cost of € 29.441.739,50.

Table 1. SESAR Projects on Situational Awareness and Human-AI Teaming

Project Id	Project Type	Status	Project Duration	Total Cost
MALORCA	Exploratory research	Completed	2016-04-01 > 2018-03-31	€ 805.587,50
AISA	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 990.125,00
HAAWAII	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 1.825.000,00
MAHALO	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 997.212,50
TAPAS	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 997.410,00
ARTIMATION	Exploratory research	Completed	2021-01-01 > 2022-12-31	€ 999.375,00
CODA	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 2.149.690,00
TRUSTY	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 999.967,50
JARVIS	Industrial research	Ongoing	2023-06-01 > 2026-05-31	€ 15.762.359,50
AWARE	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 1.940.625,00
DIALOG	Exploratory research	Ongoing	2024-09-01 > 2027-02-28	€ 1.974.387,50

MALORCA advanced automatic speech recognition technologies by integrating AI to reduce the controller workload and increase operational efficiency through improved accuracy and robustness. AISA developed an AI-based situational awareness system that integrated high-integrity operational data, knowledge-based reasoning, and ML techniques to deliver an enriched real-time operational picture to air traffic controllers. HAAWAII developed a ML-based speech recognition architecture tailored to complex airspace regions, significantly reducing word error rates and improving communication effectiveness between controllers and pilots. MAHALO designed a hybrid ML system trained on both controller performance and physiological data to support conflict detection and resolution, promoting cooperative human-AI interaction. TAPAS explored the application of explainable AI and visual analytics to improve transparency and trust in automation-

augmented ATM systems, developing strategies to address AI interpretability issues. ARTIMATION tackled transparency challenges by utilizing data-driven storytelling and immersive analytics to enhance the explainability of automated systems, thereby fostering improved understanding and trust among controllers. CODA created a digital assistant capable of predicting future traffic scenarios while monitoring controllers' mental workload, attention, and stress levels, thereby enabling adaptive support based on real-time cognitive states through explainable AI methods. TRUSTY concentrated on increasing trustworthiness in AI-powered decision-making within remote digital tower operations, employing information visualization techniques to support human-machine interaction and decision validation. AWARE aims to enable human-machine collaboration through an artificial situational awareness system that allows AI to anticipate and respond to human needs by understanding human intent and goals. JARVIS develops three AI-based solutions, one of which is an ATC digital assistant to support more efficient and green tower operations, alongside an airborne digital assistant to assist crew and single-pilot operations, and an airport digital assistant to increase automation for safety and security in intrusion detection scenarios. DIALOG focused on enhancing human-AI collaboration by developing an AI-powered assistant that anticipates the timing and nature of support required by controllers, leveraging speech recognition and ML for naturalistic interaction.

3.2 Trajectory Prediction, Traffic Flow Management, and Network Optimization

The ATM involves all systems that support aircraft from departure through to landing, ensuring flight safety and efficiency. A central component of ATM is trajectory prediction, which helps identify hazardous airspace areas and avoid them, contributing to a safer flight experience [46]. Accurate trajectory prediction is essential for key ATM processes such as conflict detection, flight planning, and departure and arrival management [47]. In recent years, the integration of AI into ATM has significantly improved both safety and operational performance [48]. AI techniques, especially ML and metaheuristic algorithms, are widely used to enhance the precision of trajectory prediction and support dynamic airspace optimization, particularly under dense traffic conditions [49]. A closely related component of the ATM is airspace capacity management, which ensures that the system can accommodate traffic demand safely and predictably. Accurate capacity estimation is critical for maintaining the balance between traffic demand and airspace availability [50]. Moreover, poor capacity management can lead to costly operational disruptions, especially when factors such as weather, wind conditions, and runway availability are not properly accounted for [51]. To mitigate such challenges, air traffic flow management strategies are employed. These strategies aim to reduce delays, optimize the use of available airspace, and resolve imbalances between demand and capacity [52]. Therefore, the effective integration of trajectory prediction, AI-based optimization techniques, and robust flow management strategies is essential to achieve a more reliable, safe, and high-performance air transportation system.

As shown in Table 2, several SESAR-funded projects have been launched to harness AI technologies for enhancing trajectory prediction accuracy and optimizing traffic flow management. Among the 14 projects listed, seven have been completed and seven are ongoing. The earliest project began in June 2016, and the total combined cost of the 14 projects is €97.689.935,04. DART explored the application of ML and agent-based modeling to improve aircraft trajectory prediction and address demand-capacity balancing challenges, thereby contributing to delay reduction and enhanced planning effectiveness. START developed optimization algorithms that reduce uncertainties and create more predictable, stable, and resilient flight trajectories in ATM. ISOBAR developed an AI-driven network operations plan aimed at increasing the efficiency of traffic demand and airspace capacity management, with particular focus on mitigating weather-induced delays. SIMBAD enhanced large-scale airspace management microsimulation models through the application of ML, supporting network-level performance evaluation and decision-making. USEPE investigated ML applications for separation management during strategic and tactical flight planning, focusing on improving separation outcomes for unmanned aerial systems. ALBATROSS demonstrated the potential of combining technological and operational advancements with AI-based data analysis to enhance fuel efficiency across all phases of flight, contributing to more sustainable aviation operations. PJ18-W2 4D advanced trajectory-based operations by reducing trajectory uncertainty and augmenting airspace capacity, employing ML techniques to refine ground trajectory prediction and separation assurance tools. HYPERSOLVER designed a reinforcement learning-based “hyper solver” leveraging AI for end-to-end conflict detection and trajectory management, characterized by continuous reassessment and dynamic trajectory updates. ASTRA aims to predict and resolve hotspots much earlier than current practices by using an AI-based tool that helps optimise capacity while allowing aircraft to follow more efficient and environmentally friendly trajectories. FASTNet integrated airport operations comprehensively into the network using data technologies and AI, targeting pre-tactical and strategic planning processes to optimize demand-capacity balancing. KAIROS focused on improving the quality and reliability of meteorological information by integrating AI-enhanced live weather forecasts with advanced decision support tools, facilitating better demand-capacity balancing in air traffic flow management. ISLAND addressed the critical need for flexible, on-demand air traffic services that

reflect dynamic traffic demands, ensuring the continuity of ATM services despite disruptions, while aiming to increase en-route capacity and optimize cost-efficiency through AI-enabled operational adaptability. ORCI explored AI-based advanced automation support tools intended to increase runway throughput by optimizing vectoring instructions during arrivals within complex airspace environments. TADA utilized historical ATM data combined with ML to improve terminal airspace performance, providing tailored decision support tools for air traffic controllers.

Table 2. SESAR Projects on Trajectory Prediction, Traffic Flow Management, and Network Optimization

Variables	Project Type	Status	Project Duration	Total Cost
DART	Exploratory research	Completed	2016-06-17 > 2018-06-19	€ 598.523,75
START	Exploratory research	Completed	2020-05-01 > 2022-10-31	€ 1.999.411,25
ISOBAR	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 2.609.230,00
SIMBAD	Exploratory research	Completed	2021-01-01 > 2022-12-31	€ 1.383.556,25
USEPE	Exploratory research	Completed	2021-01-01 > 2022-12-31	€ 1.999.308,75
ALBATROSS	Large scale demonstrations	Completed	2020-12-01 > 2023-05-31	€ 6.940.247,86
PJ18-W2 4D	Exploratory research	Completed	2019-12-01 > 2023-06-30	€ 39.185.498,81
HYPERSOLVER	Exploratory research	Ongoing	2023-06-01 > 2025-11-30	€ 1.291.438,75
ASTRA	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 1.139.245,00
FASTNet	Fast track	Ongoing	2023-06-01 > 2026-05-31	€ 10.473.705,00
KAIROS	Fast track	Ongoing	2023-06-01 > 2026-05-31	€ 6.030.337,50
ISLAND	Industrial research	Ongoing	2023-06-01 > 2026-05-31	€ 21.449.959,62
ORCI	Exploratory research	Ongoing	2024-06-01 > 2026-11-30	€ 819.493,75
TADA	Exploratory research	Ongoing	2024-09-01 > 2027-02-28	€ 1.769.978,75

3.3 Automation in Communication, Navigation, Surveillance (CNS), and Safety Monitoring

Automation technologies, especially in CNS, have transformed ATM by replacing manual tasks with advanced systems that improve efficiency, accuracy, and safety. AI, especially Long Short-Term Memory (LSTM) neural networks, allows real-time analysis of aircraft surveillance data. These systems help detect conflicts early and support safer decision-making processes in automated environments [53]. CNS systems are at the core of this transformation. They provide the integrity, accuracy, and robustness needed for safe navigation, particularly in congested or complex airspace environments [54]. The modernization of the ATM depends on improvements in the CNS infrastructure, which enable reliable communication and navigation for growing air traffic demands [55]. AI algorithms process data from multiple heterogeneous sensors and sources, improving the detection and tracking of aircraft. These technologies are also essential for Urban Air Mobility (UAM) and Unmanned Traffic Management (UTM), where high-precision positioning and real-time transcription and interpretation of pilot-controller communications are vital [56]. Predictive analytics facilitate the identification of potential safety risks, allowing early warnings and actions before incidents occur. As stated in many studies [57], [58], [59], CNS technologies form the backbone of the modern ATM, directly impacting aviation safety and efficiency. The integration of AI with CNS technologies represents a paradigm shift in ATM, as intelligent systems enhance the precision, responsiveness, and adaptability of CNS functions and enable predictive, data-driven control strategies that are essential for managing future airspace complexity.

As shown in Table 3, several SESAR projects have operationalized AI-driven automation in communication, surveillance, and safety monitoring to enhance the resilience and overall performance of ATM systems. Of the eight projects listed, seven have been completed and one is currently ongoing. The earliest project commenced in October 2017, and the total combined cost of the eight projects is €14.766.843,75. TERRA defined a technical ground architecture for safe and efficient urban drone operations by utilizing ML algorithms to enable early anomaly detection and conflict prediction in complex urban airspace. NewSense explored AI-enhanced low-cost surveillance technologies such as 5G and millimeter-wave radar to improve safety and capacity in Advanced Surface Movement Guidance and Control System (A-SMGCS) operations, demonstrating practical benefits in airport surface management. BUBBLES proposed a Concept of Operations (ConOps) that incorporates conflict horizons, separation modes, and separation minima dynamically updated by AI algorithms aligned with CNS system performance. SINAPSE developed an intelligent and secure aeronautical communications network architecture based on software-defined networking and AI technologies, facilitating efficient data sharing while ensuring data privacy and cybersecurity compliance. ALARM developed an early warning system hosting platform that assimilates multi-source data from natural hazard observation systems, producing multi-hazard predictive models disseminated through aeronautical communication networks. SafeOPS investigated AI-based safety applications focused on real-time hazard prediction, concentrating on the development of a decision support tool to improve go-around maneuver

predictions and reduce risk during critical flight phases. TINDAIR aimed to develop a tactical deconfliction service for integrating unmanned aerial systems into complex airspace, featuring a conflict resolution module enhanced by an AI algorithm for real-time in-flight decision-making. CNS DSP aimed to accelerate the market adoption of CNS data services by developing and validating CNS data solutions that support unmanned aircraft system traffic management and AI integration.

Table 3. SESAR Projects on Automation in the CNS and Safety Monitoring

Variables	Project Type	Status	Project Duration	Total Cost
TERRA	Exploratory research	Completed	2017-10-01 > 2020-02-29	€ 937.000,00
NewSense	Exploratory research	Completed	2020-11-01 > 2022-10-31	€ 995.350,00
BUBBLES	Exploratory research	Completed	2020-05-01 > 2022-10-31	€ 1.893.197,50
SINAPSE	Exploratory research	Completed	2020-05-01 > 2022-10-31	€ 853.300,00
ALARM	Exploratory research	Completed	2020-11-01 > 2022-12-31	€ 991.268,75
SafeOPS	Exploratory research	Completed	2021-01-01 > 2022-12-31	€ 997.750,00
TINDAIR	Large scale demonstrations	Completed	2021-02-01 > 2022-12-31	€ 4.000.145,00
CNS DSP	Fast track	Ongoing	2023-09-01 > 2026-08-31	€ 4.098.832,50

3.4 AI Integration and Ethical Governance

The integration of AI in the ATM brings important benefits in terms of efficiency, safety, and operational performance. However, it also raises critical concerns about data privacy, transparency, and ethical governance. The success of AI systems in aviation depends largely on how well they ensure data security and privacy [60]. Particularly in the ATM, any data breach or cyberattack can reduce trust in AI-based systems and limit their acceptance among stakeholders. Therefore, compliance with data privacy regulations [61] and the effective implementation of cybersecurity measures are essential [62]. These efforts are vital for ensuring operational continuity and maintaining a secure environment across the aviation industry. The integration of AI into aviation requires updates to current regulations and new certification processes to ensure safety and reliability [63], [64]. Another critical aspect is the explainability of AI systems, as understanding how algorithms make decisions is essential for ensuring safety, building trust, and supporting acceptance [65]. However, deep learning models often function as "black boxes", meaning their internal decision-making processes are difficult to interpret [66]. This lack of transparency may increase operational risks and reduce confidence, especially in safety-critical environments such as aviation. Therefore, enhancing the explainability and auditability is essential. Ethical concerns also arise, as AI tools such as passenger screening and risk assessment may lead to unintended algorithmic bias and discrimination [67]. To prevent such outcomes, ethical guidelines should be developed and integrated into the design and implementation of AI systems in ATM.

As shown in Table 4, several SESAR projects have been launched to translate ethical and regulatory considerations into operational practices for AI integration in ATM. Two of these projects have been completed, while two are currently ongoing. The earliest project began in March 2016, and the total combined cost of the three projects is €4.969.520,00. INTUIT examined the interdependencies among key performance indicators in ATM by integrating visual analytics and ML, facilitating more informed and ethically sound decision-making processes. AICHAIN concentrated on enabling the privacy-preserving exploitation of extensive private datasets sourced from multiple stakeholders through federated learning techniques, thereby enhancing ML applications while ensuring data privacy and security. HUCAN developed comprehensive design guidelines and an implementation toolkit to streamline the development of automation and AI-powered systems, while also investigating certification strategies and regulatory challenges to ensure compliance with existing aviation safety requirements. SynthAIR project explores and defines AI-based methods to generate synthetic data, which are attractive because they require less user expertise and offer better generalization capabilities.

Table 4. SESAR Projects on AI Integration and Ethical Governance

Variables	Project Type	Status	Project Duration	Total Cost
INTUIT	Exploratory research	Completed	2016-03-01 > 2018-02-28	€ 998.125,00
AICHAIN	Exploratory research	Completed	2020-06-01 > 2022-11-30	€ 1.757.491,25
HUCAN	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 998.900,00
SynthAIR	Exploratory research	Ongoing	2023-09-01 > 2026-02-28	€ 1.215.003,75

4 Conclusion

The study has explored the integration of Artificial Intelligence (AI) and Machine Learning (ML) technologies in SESAR projects within the context of the Single European Sky (SES) initiative. The analysis covered 37 SESAR projects, identifying key patterns of AI/ML applications across four thematic areas: situational awareness and human-AI teaming; trajectory prediction, traffic flow management, and network optimization; automation in communication, navigation, surveillance (CNS), and safety monitoring; and AI integration and ethical governance.

The findings indicate that AI/ML technologies are being increasingly adopted to support core Air Traffic Management (ATM) functions. These technologies enhance system performance, reduce controller workload, and improve decision-making through predictive and adaptive tools. In particular, trajectory prediction and automated conflict resolution benefit significantly from ML-based models, while natural language processing and speech recognition enable more efficient human-machine communication.

Furthermore, ethical concerns such as transparency, trust, and human oversight have been addressed in several SESAR projects. This reflects the growing importance of responsible AI use in aviation and aligns with international discussions on AI governance.

The study has a notable limitation in terms of geographical scope. It focuses exclusively on ATM AI/ML applications within the SESAR program, which reflects the European perspective on ATM modernization. While SESAR is widely recognized as a globally leading initiative in ATM innovation, and its project documentation provides extensive, structured, and publicly accessible data for in-depth analysis, similar access is not available for non-European programs. For instance, the United States' Next Generation Air Transportation System (NextGen) focuses on digitalizing air traffic operations; Australia's OneSky initiative aims to integrate civil and military ATM under a unified system; Brazil's SIRIUS program targets the development of an integrated ATM framework tailored to its large territory; and Japan's Collaborative Actions for Renovation of Air Traffic Systems (CARATS) initiative promotes long-term innovation in ATM through stakeholder collaboration and advanced technologies. However, the lack of publicly available, project-level documentation comparable to the SESAR portal limits the feasibility of a systematic cross-regional analysis. As a result, while the findings offer valuable insights into AI/ML use in European ATM, they may not fully capture developments occurring in other regions.

Future research could examine how AI/ML tools used in SESAR projects perform in real operational settings. A key area would be the interaction between humans and automation, especially how AI systems affect air traffic controllers' workload, decision-making, and trust. Another important direction is the assessment of data privacy and cybersecurity in operational AI systems. Aviation involves highly sensitive data, and any security breach could damage trust in AI tools. Research should evaluate how well current systems align with privacy policies and whether cybersecurity measures are sufficient. It is also important to study how understandable these AI systems are. Many of them work like a "black box", making it hard for users to know why a decision was made. In a safety-critical field like aviation, improving explainability can help increase confidence and reduce risks. Finally, ethical concerns such as algorithmic bias should not be overlooked. AI systems that process personal or operational data may unintentionally lead to unfair outcomes. Future studies could explore ways to detect and reduce bias, ensuring fairness and accountability in AI-supported decisions. These areas would help build a more complete picture of how AI can be safely and responsibly used in air traffic management. Overall, this study contributes to a deeper understanding of how AI and ML are shaping the future of ATM in Europe and lays the groundwork for broader, comparative research on intelligent aviation systems worldwide.

Conflict of interest

The author has no conflict of interest to declare.

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