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The Future of AI in Air Traffic Management: Coordinating Autonomous Airliners and UAM within Busy Airspaces using AI

Seminar Paper

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Affidavit

I certify that I have completed the work without outside help and without using sources other than those specified and that the work has not yet been submitted in the same or a similar form to any other examination authority and has been accepted by them as part of an examination. All statements that have been adopted literally or analogously are marked as such.

Ingolstadt, 6 May 2025

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Abstract

The summary gives the reader a rough overview of the content (brief problem definition, approach, solution approaches and possibly key findings). The scope should be about half a page. This chapter is not mandatory and should only be considered optional.

Contents

1 Introduction

1.1 Artificial Intelligence

Artificial intelligence (AI), along with its subfields machine learning (ML) and deep learning (DL), has emerged as fundamental tools in the modernisation and optimisation of various industries, including aviation [1]. ML involves the development of algorithms and models that enable computers to learn from data and make informed decisions without being explicitly programmed [1]. DL, a subset of ML, utilises artificial neural networks that mimic the structure and function of the human brain to process complex patterns and large datasets [1]. In combination with AI-driven tools such as natural language processing (NLP) and computer vision, , these tools are being integrated across a wide range of aviation applications, from flight operations and maintenance to passenger services and air traffic management [1].

1.2 Urban Air Mobility

According to European Union Aviation Safety Agency (EASA), urban air mobility (UAM) refers to an air transportation system for passengers and cargo in urban environments, with the transportation performed by an electric aircraft capable of vertical takeoff and landing (VTOL), either remotely piloted or with a pilot on board. Commercial operations in European cities are expected to begin as early as 2025, with initial applications focusing on drone-based goods delivery and passenger transport using piloted aircraft [2]. Several pilot projects are currently underway. European manufacturers such as Airbus, with its CityAirbus NextGen, and Volocopter, with its VoloDrone, are actively developing and testing aircraft designed for both passenger and cargo transport [3].

The anticipated benefits of UAM include faster and more sustainable transportation, reduced congestion, and extended urban connectivity. However, major concerns remain regarding safety, environmental impact, noise pollution, and cybersecurity. Public acceptance and user confidence will be critical factors for the successful implementation of UAM in Europe [4].

Currently, many UAM vehicles are in the development or testing phase, with a long-term objective of achieving fully autonomous operations using unmanned aerial vehicles (UAVs) [5].

1.3 Autonomous Airlines

Autonomous airliners represent a branch of UAVs, consisting of fixed-wing aircraft capable of flying and navigating without direct intervention of a human pilot. Although modern commercial airliners already automate approximately 93% of flight functions, such as autopilot systems and Automatic Dependent Surveillance-Broadcast (ADS-B), there remains a growing demand to implement higher levels of autonomy. Increased automation is seen as a path toward enhanced safety, greater scalability, and improved affordability.

Human error is cited as the leading cause in approximately 80% of general aviation accidents. As a result, the vision for autonomous airliners includes minimising single points of failure in both design and operation by removing the human from direct aviate-navigate-communicate roles and replacing them with reliable, intelligent automation [6].

While fully autonomous aircraft are technically feasible today, they have not yet been deployed for public use [6]. This limited adoption can be attributed to several key factors [7]:

a) public acceptance rates remain below the 50% threshold typical for early adopters of innovative technologies,

b) persistent public trust in the value of direct human pilot presence and intervention, and

c) unresolved regulatory and cybersecurity concerns.

1.4 Air Traffic Management

Air Traffic Management (ATM) refers to the systems and services that ensure the safe anf efficient movement of aircrafts during all phases of operations, through controlled airspaces and on the ground at airports [8]. It comprises serveral components, including Air Traffic Control (ATC) (its main component), Airspace Management (ASM), Air Traffic Flow Management (ATFM), and Air Traffic Service (ATS) [9].

Air Traffic Controllers (ATCOs) are responsible for directing aircraft safely and efficiently, managing takeoffs and landings, maintaining safe distances between aircraft en route and handling emergencies. Their role demands high levels of situational awareness, rapid decision-making, and the ability to manage multiple tasks under high stress conditions. These indispensable skills, such as judgement, flexibility and the ability to handle unexpected situations, remains critical and are not easily replicated by automated systems, despite advancements in digitalisation [10].

However, the rapid expansion of commercial aviation, UAM, and UAVs have significantly increased the complexity of ASM [11]. With air traffic volume increases, the scalability of the system is limited by the finite capacity of ATCOs, who are subject to workload constraints and cognitive overload [12]. Fatigue and informaion overload have become key contributors to operational inefficiencies and potential safety risks [11]. Furthermore, human limitations in reaction time and decision-making speed highlight the need for intelligent, automated support systems that can enhance overall system performance.

Integrating UAM into air traffic flow poses a significant challenge due to their unique performance characteristics, which differ from those of fixed-wing aircraft. These differences can lead to suboptimal use of airport capacity [9]. Compounding the issue is the current shortage of ATCOs, alongside the long training periods required to qualify new personnel, this has amplified the demand for AI-based solutions in ATM. AI technologies are able to solve these challenges through real-time data processing, predictive analytics, and autonomous decision-making capabilities [11]. While some automations already exist in some areas [13], existing systems often rely on rigid rule-based frameworks and lack the flexibility and adaptability needed for dynamic environments [12].

The integration of UAV into ATM has led to the development of a new branch known as UAS traffic management (UTM). As UAVs often operate across both controlled and uncontrolled airspaces – and ATCOs are only responsible for controlled airspaces – a key challenge arises: there is no ATC service in uncontrolled airspaces. This lack of oversight increases the risk of mid-air collisions or accidents involving other UAVs, manned aircraft, ground vehicles, or natural and artificial obstacles. Therefore, a dedicated system like UTM is essential to ensure safe and efficient UAV operations in all types of airspace [14].

The integration of UAM and UTM into the existing ATM framework will not only stress current infrastructure but also require faster, more adaptive decision-making [15] – an area where AI technologies can provide substantial value.

This report explores the roles of AI in shaping the future of ATM, focusing particularly on its application to autonomous airliners and UAM integration.

2 Role of AI in Future ATM

Given the increasing complexity of ASM, AI is now a fundamental enabler of next-generation ATC systems. AI-driven automation and decision-support tools help metigate risks, reduce operational inefficiencies, and enhance safety [11]. Main research focuses are on traffic, trajectory, performances, airports, weather, accident, fuel, passenger, and time [1]. The following are reasons why AI is indispensable for modern ATC.

2.1 Real-Time Decision Support and Conflict Resolution

AI-powered decision-support systems process vast amounts of real-time data to assist ATCOs, enabling faster and more precise conflict detection and resolution that align with ATCO's typical strategies [11]. Its key advantage over traditional approaches lies in their ability to automate repetitive tasks that typically consume time and cognetive resource, reducing the workload of ATCOs , allowing them to focus more effectivly on complex, unpredictable challenges that demand higher-level decision-making skills [12]. An example is the Interactive Conflict Solver (iCS), which involves ATCOs to generate conflict scenerios and learning from their resolution strategies [12].

2.2 Predictive Analytics for Traffic Flow Optimisation

AI algorithms can forecast traffic congestion patterns using historical and real-time flight data, with Graph Neural Networks and Transformer models optimising airspace sectorisation dynamically [11]. Two main research areas have been identified: trajectory and path planning, and separation and sequencing.

2.2.1 Trajectory and Path Planning

Trajectory and path planning allows aircraft to autonomously adjust paths in real time, improving scalability compared to traditional centralised methods [1]. AI enhances 4D trajectory planning by enabling real-time dynamic re-planning during flight, responding to traffic, weather, or air space restructions without manual interventions. These AI systems continously optimise routes based on live data, balancing fuel efficiency, flight time, and safety [12].

2.2.2 Separation and Sequencing

Tools are developed to tackle the Arrival Sequencing and Scheduling Problem (ASSP), with techniques such as time-based separation (TBS) and particle swarm optimisation (PSO) to optimise arrival order and timing, reducing delays at busy airports. Tunnel Gaussian Process (TGP) model helps maintain safe distances between aircrafts, even under uncertainty. while offering insights to flight dynamics during the final approach [12].

2.2.3 Meteological and environmental factors

Severe weather conditions such as storms, turbulence, and wind shear create safety risks for aircraft. Traditional weather forecasting models struggle to provide precise, real-time impact predictions for ATC decision making [11]. AI prediction systems are developed to combine radar and weather data, aiding in route planning and reducing weather-related delays. Advanced visualisation techniques, such as five-dimensional displays, provide ATCOs with real-time views of weather conditions and trajectory data, improving situational awareness [12].

2.3 Intelligence Communication Between Pilots and Controllers

AI-driven speech recognition systems (e.g. Large Language Model (LLM)-powered) transcribe and interpret ATC communications. Such models like OpenAI o3 and Gemini 2.0 reduce misunderstandings and improve controller-pilot interactions [11].

2.4 AI-Driven Automation for UAS

AI enables autonomous UAV traffic management, preventing conflicts between manned and unmanned aircraft. Multi-Agent Reinforcement Learning (MARL) enhances swarm intelligence for unmanned aerial system (UAS) coordination.

2.5 Enhancing Safety through AI-Powered Surveillance and Monitoring

AI-based radar and satellite tracking improve aircraft detection and monitoring. Computer Vision models analyse runway occupancy and ground movement for airport safety.

3 Vision of Future ATM

Future [16]

4 Challenges and Risks

Challenges [13]

5 Conclusion

Acronyms

ADS-B Automatic Dependent Surveillance-Broadcast. 1, 3

AI artificial intelligence. 1, 3–6

ASM Airspace Management. 2, 4

ASSP Arrival Sequencing and Scheduling Problem. 5

ATC Air Traffic Control. 2–5

ATCO Air Traffic Controller. 2–5

ATFM Air Traffic Flow Management. 2

ATM Air Traffic Management. 2–4

ATS Air Traffic Service. 2

DL deep learning. 1

EASA European Union Aviation Safety Agency. 1

iCS Interactive Conflict Solver. 4

LLM Large Language Model. 5

MARL Multi-Agent Reinforcement Learning. 5

ML machine learning. 1

NLP natural language processing. 1

PSO particle swarm optimisation. 5

TBS time-based separation. 5

TGP Tunnel Gaussian Process. 5

UAM urban air mobility. 1–4

UAS unmanned aerial system. 5

UAV unmanned aerial vehicle. 1–3, 5

UTM UAS traffic management. 3

VTOL vertical takeoff and landing. 3

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