Technische Hochschule Ingolstadt

Faculty of Computer Science

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, 9 May 2025

Signature

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 Urban Air Mobility

1.1 Introduction

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 [**easa_uam**]. Example of UAM aircrafts include electric VTOL (eVTOL) aircraft like the VoloCity (developed by Volocopter) and CityAirbus NextGen (developed by Airbus) [**gomez2024uam**]. Many European manufacturers are actively developing and testing aircrafts designed for both passenger and cargo transport [**gomez2024uam**]. Starting from 2025, Commercial operations in European cities are expected, with initial applications focusing on drone-based goods delivery and passenger transport using piloted aircraft [**easa_uam**].

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 [**easa_uamlandscape**].

1.2 Unmanned Aerial Systems

Unmanned aerial system (UAS) is a branch of UAM, with aircrafts with no direct intervention from human pilot. It is also referred to as drones, and consists of three components: (1) an unmanned aerial vehicle (UAV), (2) an autonomous or human-operated control system, and (3) a command and control (C2) system (sometimes referred to communication, command, and control (C3) system) [**skybrary_uas**]. An UAV is an aircraft that operates or is designed to operate autonomously, or to be pilot remotely without a pilot onboard [**skybrary_uas**].

Currently, it is being used for security surveillance, emergency response, small package and bulk cargo transport, and furthermore [**skybrary_uas**]. Its use cases is not listed exhaustively here.

1.3 Autonomous Airliners

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.

2 Air Traffic Management

2.1 Introduction

Air traffic management (ATM) is the aggregation of the airborne and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations, through controlled airspaces and on the ground at airports [**skybraryATM**]. It comprises serveral components, including air traffic service (ATS), airspace management (ASM), and air traffic flow management (ATFM) [**skybraryATM**]. Figure 1 shows the structure of ATM and relations between ATS, ASM, and ATFM.

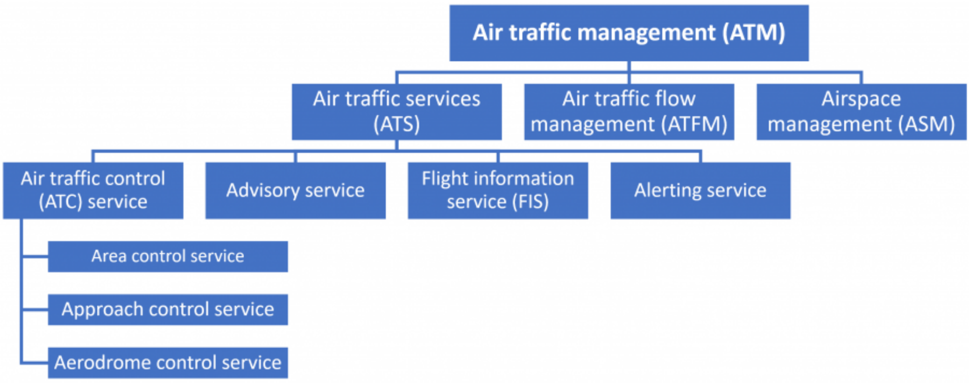

Figure 1: Structure of ATM [**skybraryATM**]

Air traffic controllers (ATCOs), part of air traffic control (ATC) service, 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 [**eurocontrol2024digitalisation**].

2.2 Challenges with Integrating UAS to current ATM

The rapid expansion of commercial aviation, UAM, and UAVs have significantly increased the complexity of ASM [**Ramachandran_2025**]. 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 [**Meier_2024**]. Fatigue and informaion overload have become key contributors to operational inefficiencies and potential safety risks [**Ramachandran_2025**]. 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 [**Schuchardt_2023**]. 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 artificial intelligence (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 [**Ramachandran_2025**]. While some automations already exist in some areas [**skybrary2025automation**], existing systems often rely on rigid rule-based frameworks and lack the flexibility and adaptability needed for dynamic environments [**Meier_2024**].

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 [**Zsolt_2017**].

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 [**Rumba_2020**] – an area where AI technologies can provide substantial value.

3 Future of AI in ATM

3.1 Safe Flight Pathing Through Hazardous Sky

Natural events such as thunderstorms and volcanic ash clounds present safety challenges for the aviation section. In addition, aerosols and gases arising from natural hazards such as forest fires and desert dust can also severely reduce visibility and damage engines. Even space weather, such as the solar wind, can impact aviation by disrupting satallite communication and increasing radiation exposure.

The multi-hAzard monitoring and earLy wARning systeM (ALARM) project was funded within the framework of the Single European Sky Air traffic Research system (SESAR) Joint Undertaking to move the aviation sector towards mordenising Europeans glsATM system by developing a prototype monitoring and early warning system for various hazards. To achieve this, near real-time data from ground-based and satellite systems was gathered. This highly granular information was then processed and fed into models for identifying the displacement of particles and gases derived from natural hazards, as well as extreme weather situations. The first step is to provide a snapshot of what is happening, then to develop predictive models that is able to provide the aviation sector with forecasts of between one hour ahead and a day ahead. To achieve this, AI was applied to observational data and historical observation and create a model that is able to learn from past localised forecasts and weather observations, in order to be able to better predict the likely evolution of any given natural event. This model can be used, for example, to accurately predict the behaviour of severe thunderstorm over an airport, and ATCO can use this information to make in-flight deviations or reschedule flights altogether.

[**cordis2022aiatm**]

3.2 Maintain optimal airfraft separation in airspace

In a research by Liu [**LIU2021100058**], a routing optimisation model was proposed to be used independently by multiple routing agents that allows real-time dynamic allocation of airspace volumes withr obust mechanisms for conflict resolution. Safety standards held equal, a traffic management system built on this model can support more concurrent flights in a given volume of airspace than what existing systems are capable of, thus allowing more goods to be transported via automated aerial delivery.

In this system, each agent represents a USS executing central control over its own fleet of UAVs. Multiple agents passively interact with each other via observing and reacting to the motion of each other's fleets. No complicated inter-agent communication is required to achieve harmonious traffic outcomes. UAVs within the same fleet are cooperative, while UAVs across different fleets are semi-cooperative – they share the same goal of maintain safe separation, but do not communicate flight intents or negotiate right of ways as do UAVs manage by the same USS.

While centralised traffic management is most conducive to efficient point-to-point air trips, the practical reality demands a more flexible architecture in which multiple private fleets can operate independently, yet harmoniously, in shared airspaces. Sufficient separation is the most fundamental operating requirement shared among all airspace users, but how to maintain the desired level of separation in a decentralised operation environment is a core challenge to be addressed.

3.3 Automatic Speech Recognition and Understanding (ASRU)

Voice communication between ATCOs and pilots using radio equipment is still the main communication channel used in air traffic control, with ATCOs issue verbal commands to the cockpit crew. Whenever the information from the voice communication has to be digitalised, ATCOs are burdened to manually enter the information, although it was already uttered. On one hand, Automatic Speech Recognition (ASR) transform the analog voice signal into spoken sqeuence of words. On the other hand, Automatic Speech Understanding extracts the meaning from the sequence of words, .

When the formal problems of representing lexical syntatic, and semantic information are solved, the spoken call signs still need to be extracted from a verbal transmission. + noisy environment with diffrent spoken accents

Another application of ASRU is the pre-filling of radar labels with information extracted from ATCOs voice transmissions.

3.4 Cybersecurity

Security threats to civil aviation operations have become more sophisticated and challenging. Cyber attacks are increasing in quantity and persistence, so the consequences of a successful malicious cyber-attack on civil aviation operations could be severe nowadays. In ATM, the reliance on computer-based and information technology systems is expected to grow with new and modern airports being developed, new aircrafts introduced into service and stakeholders seeking to meet the demands of the growing demand of the more IT-savvy passengers with new passenger facilitation process, using digital and IT-based systems.

3.5 Autonomous UTM

4 Conclusion and Outlook

Acronyms

ADS-B automatic dependent surveillance-broadcast. 2

AI artificial intelligence. 3

ASM airspace management. 2

ATC air traffic control. 2, 3

ATCO air traffic controller. 2, 3

ATFM air traffic flow management. 2

ATM air traffic management. 2, 3

ATS air traffic service. 2

EASA European Union Aviation Safety Agency. 1

eVTOL electric VTOL. 1

UAM urban air mobility. 1–3

UAS unmanned aerial system. 1

UAV unmanned aerial vehicle. 1–3

UTM UAS traffic management. 3

VTOL vertical takeoff and landing. 1