Human-AI Teaming in the Urban Air Mobility Coordinator Work Position: A Proof-of-Concept Design

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Abstract. Drones and vertical take-off and landing aircraft are set to revolutionise mobility in cities, necessitating advanced traffic management solutions for the low-level U-space airspace. The transition from piloted to autonomous operations will require a shift from traditional air traffic management to highly automated systems, while human oversight remains critical for handling emergencies and operational uncertainties. This paper presents a proof-of-concept design for a Urban Air Mobility (UAM) Coordinator work position, where a human operator collaborates with an AI-based Digital Assistant (DUC) to manage futuristic U-space operations in Stockholm, Sweden. The study explores the feasibility, challenges, and opportunities of U-space traffic management while examining effective human-AI teaming. The proposed UAM Control Centre, operating under a U-space Service Provider, integrates 25 U-space services, balancing automation with human oversight. The design of the workstation includes a three-screen interface for situational awareness, communication, and decision support. The DUC improves efficiency by managing routine tasks like conformance monitoring, while the UAM Coordinator focusses on strategic decision making. Developed through a two-year co-design process with air traffic management and U-space experts, this concept aligns with European U-space regulations. Future simulations will further evaluate the performance of the DUC in improving safety and efficiency. The study advances the development of human-centric Human AI-Teaming (HAT) solutions to enhance safety and efficiency in safety-critical environments, with a particular focus on complex urban airspaces.

Keywords: Human-AI Teaming · Teamwork · Transparency · Situation Awareness · UAM · UAS · U-space

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1 Introduction

Drones and vertical take-off and landing (VTOL) aircraft are anticipated to transform mobility for people and goods in the coming decades, requiring new and advanced traffic management solutions for the U-space (i.e., low-level airspace over cities and rural areas). The emerging framework and terminology for advanced air mobility (AAM) [1], which encompasses Urban Air Mobility (UAM) and Uncrewed/Unmanned Aircraft Systems (UAS), has been expected to go live in 2025, initially with human pilots, and transition to autonomous operations by 2030 [2]. While traffic management procedures will evolve from current air traffic management (ATM) procedures, the expected traffic densities and complexity of urban airspace will require increased dependence on advanced technology, making traditional ATM solutions insufficient. Mature U-space operations are anticipated to be highly automated, although human involvement may remain crucial for managing emergencies, handling non-normal situations, and addressing cases with operational unpredictability [2,3]. A key challenge for the safety and social acceptance of U-space operations [2,4] is to effectively handle such situations, given the proximity to civilians and the urban environment, where suitable landing sites are limited.

In Europe, the U-space Service Provider (USSP) is expected to take on many traditional ATM functions to provide U-space services. [2]. In USA, a similar function called the Provider of Services to UAM (PSU) would be responsible for managing information services for UAM operators. From the industry side, the UAM solution provider EVE Air Mobility argues that there is a need to introduce a new “Airspace Manager” role to oversee safety, security, capacity, and fair airspace use [5] (p. 67). AI-powered systems can offer advantages in supporting human operators in traffic management tasks such as handling larger traffic volumes and monitoring air and ground activities for trajectory planning.

We propose the UAM Coordinator as a central safety and coordination function working for the U-space Service Provider [2] in an UAM Control Centre (UCC). This paper presents a proof-of-concept design for a UAM Coordinator work position, where a human operator and AI-based system collaborate to manage airborne traffic in a future U-space over Stockholm, Sweden. The proof-of-concept design has three novel components: the human *UAM Coordinator*, the *AI-based Digital Assistant for UAM Coordinator (DUC)*, and a *multi-display workstation* with three screens and a communication system.

Our proof-of-concept design has two objectives: First, imagine and explore in a prototype working environment what U-space traffic management could look like in a major European city, offering stakeholders insight of its feasibility, challenges, and potential opportunities for implementing U-space operations. Second, investigate how human and intelligent assistant teams can be formed to collaborate effectively in safety-critical working environments, using specific scenarios of U-space operations in Stockholm as case studies to explore. For the unfamiliar reader and due to the variations in terminology used internationally for U-space and UAS/UAM, a glossary of the terms used in this paper is provided in Appendix A.1

2 Theoretical Foundation

The design process for our prototype uses theories and related work on Human AI-Teaming (HAT). After first providing an overview of the theories in this concept as well as application of them, we lay out our theoretical model used in the presented work.

2.1 HAT Theory

The teaming between humans and machines is commonly referred to synonymously as human-AI or human-autonomy teaming, abbreviated as HAT [6–8]. HAT consists of at least one human and one autonomous agent [9]. In aviation, EASA [10] categorises HAT into cooperation (AI follows predefined tasks) and collaboration (AI and humans solve problems with shared goals). Collaboration requires AI to share situation awareness, adapt, evaluate human solutions, and engage in negotiation and argumentation. A report by the National Academies of Sciences, Engineering, and Medicine [7] identified key challenges and gaps in HAT, including aspects such as team models, interaction, trust, and transparency. Effective HAT require humans to understand and predict AI behaviour, build trust, make decisions based on AI input, and exert timely control.

The design and development of a successful and efficient HAT is believed to be influenced by several factors. Endsley [8] emphasises that situational awareness is crucial for effective interaction and system supervision within HAT. She presents a framework to define the information that must be shared within the team, highlighting three key aspects: taskwork awareness (understanding the system and environment to support task performance), agent awareness (of oneself and teammates to enable intervention and backup), and teamwork awareness (ensuring integration, coordination, and cooperation within the team). Transparency, defined as the ability of automation to enable understanding and predictability [11], is considered essential for trust and situation awareness, with Explainable AI (XAI) providing methods for clarity on AI reasoning and outcomes [7,8,12]. Another crucial factor influencing HAT efficiency is the degree to which team members can engage in bidirectional communication to share intent, discuss, and align on goals [6,13,14].

2.2 HAT Applications

Previous research has explored HAT in the context of aviation, UAS and ATM. In the context of UAS operations, McNeese et al. [15] studied HAT by comparing three team configurations in which a human participant worked with a synthetic pilot, and inexperienced human pilot, or an experienced experimenter pilot. The study assessed team performance, target processing efficiency, situational awareness, and verbal behaviour. Although the synthetic team performed on par with human-based teams, challenges emerged in developing effective coordination strategies and anticipating information needs between human and synthetic agents.

Westin et al. [16] introduce the Digital Tower Assistant (DiTA), designed to support tower controllers in managing multiple remote tower operations. Their study, based on early concept development and paper-based gameplay evaluations with ATCOs, highlighted concerns about the system's operational boundaries and limitations. Expanding on this work, Palmerius et al. [17] had interaction designers analyze interviews with ATCOs after simulator tests where they interacted with a DiTA prototype in managing two airports simultaneously. A key finding was the importance of automation transparency and predictability.

Battiste et al. [14] implemented a human-AI teaming (HAT) model in an electronic flight bag (EFB), incorporating transparency, bidirectional communication, and human-directed execution for single pilot operations. The HAT was designed to assist with diversion decisions during off-nominal flight scenarios. Flight simulator tests with pilots indicated that working with HAT automation facilitated decision making and reduced workload.

Jameel et al. [18] proposed a working position prototype of a Digital Air Traffic Controllers (ATCO) assistant teaming up with an ATCO to manage en-route control. The prototype architecture included a radar display for traffic visualisation, the Digital Interactive Radar Controller (DIRC) as the AI teammate, a HAT interface for communication, a data and service integration module for information management, and automation tools for (ATC) tasks. Interaction with DIRC was enabled through a dedicated interface adjacent to the radar display, featuring HAT mode selection (activation/deactivation of DIRC), a command log to track DIRC activities, and a flight strip overview that displays flight statuses and control assignments (DIRC or ATCO).

The EU-funded HAIKU project (https://haikuproject.eu/) explores HAT in aviation by developing and evaluating six intelligent assistant prototypes across six distinct use cases. The UAM Coordinator work position presented here specifically examines the UAM and U-space use case (while the other cover flight deck, tower control, and airport operations). HAIKU aims to develop human-centric AI that supports safe and effective operations while maintaining human autonomy and optimising human-AI teamwork. Two core principles guide this approach: preserving human autonomy by ensuring AI enhances rather than replaces human roles, preventing loss of engagement and situational awareness; and enabling effective HAT, where working together improves overall system performance rather than merely substituting human tasks with automation, requiring effective bidirectional communication.

Lundberg and Johansson [19] propose a framework for joint control for autonomous, automated, and manual control systems. Based on this framework, Nylin [20] developed the Reduced Autonomoy Workspace (RAW) concept, which emphasises the need for effective communication within HAT, even when agents operate at different levels of cognitive control. For example, in ATC, automation continuously monitors aircraft altitude, speed, and headings, while the ATCO focusses on defining strategic goals and making trade-offs based on the broader operational impact of different decisions.

2.3 Our Theoretical HAT Model

Research on HAT highlights the challenges in establishing shared situational awareness, ensuring transparency, enabling clear communication, and fostering effective decision making. From the literature, we have based our HAT theoretical model on four pillars. The specific DUC HAT requirements identified for each construct are provided in Appendix A.2.

Situation Awareness. Situation awareness can be defined as the perception of elements in the environment over time and space, the comprehension of their meaning, and the projection of their future status [21]. The DUC and the UAM Coordinator must be capable of establishing their own situation awareness and then derived a shared situation awareness.

Bidirectional Communication. Bidirectional communication is the exchange of information in both directions between two parties, enabling both to send and receive knowledge and intent. DUC and the UAM Coordinator must be able to communicate efficiently and effortlessly to share information, goals, and strategy.

Transparency/Explainability. Automation transparency can be defined as: the automation's ability to afford understanding and predictions about its behaviour [11]. Explainable AI applies specifically to advanced automation based on AI technologies and focusses on affording understanding about its actions and decision-making processes [7]. The UAM Coordinator must understand how DUC works (input-output relationships), what it can do (and not do), what DUC is doing, and why DUC is doing/suggesting something. In safety-critical systems such as aviation and healthcare, AI applications must be transparent and traceable to gain operator trust and acceptance. Systems with opaque logic and reasoning, often referred to as "black-box" AI, are not suitable, as they hinder understanding and accountability.

Decision Making. Decision-making refers to the cognitive process of selecting a course of action from several alternatives based on evaluation, judgment, and reasoning, often to achieve a specific goal or outcome. The DUC and the UAM Coordinator must be able to work together to solve problems and make and implement decisions. There must be clear roles and responsibilities.

3 Design Process

The UAM Coordinator working position concept has been developed over a two-year period using a combined co-design approach and a scenario-based approach in close collaboration with (ATCOs) and subject matter experts in U-space, UAM, UAS, and UAS Traffic Management (UTM) from the Swedish Air Navigation Service Provider. The concept development process followed a series of structured steps:

- Determine the operational environment baseline (i.e., U-space ConOps).
- Define the U-space for Stockholm City as a testbed for implementing the UAM Coordinator work position.
- Develop realistic traffic scenarios to study HAT in U-space operations.
- Implement Stockholm U-space and scenarios in the UTM City simulation platform.
- Identify tasks, roles, and responsibilities of the UAM Coordinator and the DUC, using the defined scenarios as examples.
- Define the HAT dynamics to outline how the UAM Coordinator and the DUC will collaborate in traffic management, using the established scenarios as examples.

This iterative research has resulted in the UAM Coordinator working position concept, the implementation of a Stockholm U-space and four traffic scenarios in UTM City. Table 1 presents the key research activities in chronological order, along with their main contributions to the concept development.

The first step was to define the operational environment for low-level urban drone traffic. With no current drone operations established, our first step was to define a ConOps for the envisioned real-world U-space environment. An initial literature review of nine UAM/UAS and U-space concepts identified the European CORUS-XUAM ConOps as a baseline ConOps (concepts reviewed include: CORUS-XUAM [2] UATM [3,5,22], UTM/UAM [23], and NASA UAM [24–27]). CORUS is a Horizon 2020 project funded by the SESAR Joint Undertaking that has addressed U-space ConOps, starting in 2017 (currently in its fifth iteration), with the fourth iteration focussing on integrating UAM with the U-space. It confirmed that U-space traffic management is moving towards high automation, with human involvement primarily needed for managing non-normal and emergency situations. Based on the CORUS-XUAM ConOps, three domain experts from the Swedish ANSP, LFV, defined a U-space airspace for the Swedish capital of Stockholm. Stockholm was chosen as the testbed because of its scale and relevance for future UAM operations. The researchers then implemented the U-space definition for Stockholm on the UTM City platform.

Once the U-space airspace had been defined, the scenario-based design approach focused on identifying realistic scenarios to guide development of the UAM Coordinator working position ConOps, prototyping solutions, and allow for testing it with target end-users in low-fidelity simulations. Two scenarios were identified from interviews with EVE Air Mobility, a UAM solution provider. The scenarios were tested in a human-in-the-loop simulation with eight ATCOs. The study highlighted the need for better structuring the coordination and tasks between the UAM Coordinator and the DUC.

Subsequent workshops and interviews with industry experts and operators (e.g., with EVE Air Mobility and the Drone Unit) refined the tasks, roles, and interactions between the UAM Coordinator and the DUC. A key insight was a better understanding of the role of the UAM Coordinator and its reactive nature (in contrast to ATCOs who work proactively), requiring rapid development of situation awareness and effective multimodal communication. These activities

Table 1. Research activities, their purpose and main contribution

Activity	Purpose	Outcome
Literature review of UAS, UAM, and U-space Concepts	Identify the U-space ConOps to build scenarios in and investigate the need for a human role in U-space traffic management	CORUS-XUAM was identified as reference ConOps for Stockholm. U-space Services in CORUS-XUAM informed UAM Coordinator and DUC high-level tasks
1st interview with EVE Air Mobility (UAM Solution Provider)	Gather feedback on their U-space ConOps, future traffic scenarios, and human roles in U-space traffic management	Shaped Stockholm U-space, identified reference scenarios (e.g., medical emergency), and refined human role concepts
Simulation with ATCOs (N = 8)	Extract perceptions and feedback on scenarios, UAM Coordinator role, and DUC	Provided insights into operator expectations and role feasibility
Interview with Drone Unit (Eurocontrol Innovation Hub) and CORUS-XUAM	Inform scenario design, human roles, and intelligent assistant functionalities	UAM Coordinator is a safety function supported by DUC
Field study to Joint Rescue Coordination Center (Sweden) and interviews with Rescue Leaders	Understand the nature of work in emergency coordination and its similarities to the UAM Coordinator role	Aligned UAM Coordinator role with real-world emergency coordination practices. Shaped UAM Coordinator work position comprising three screens
2nd interview with EVE Air Mobility (UAM Solution Provider)	Gather feedback on Stockholm U-space implementation, scenarios, UAM Coordinator role, and DUC	Improved scenario realism, new scenarios (e.g., fire affecting vertiport and airspace), and refined human role and DUC functionalities
Workshop on DUC and UAM Coordinator teaming (N = 8)	Define task distribution, coordination, and communication between DUC and UAM Coordinator in various scenarios	Clarified key competencies, structured HAT via checklists, need for multimodal communication, and refined DUC capabilities for monitoring and prioritisation
Workshop on AI applications for DUC (N = 19 subject matter experts)	Brainstorm AI/ML methods applicable to DUC and identify problems AI can solve	Identified possible AI applications for DUC, categorizing tasks into autonomous, shared, and assisting capabilities
Task and process analysis to derive Operation sequence diagrams (OSD)	Analyse three scenarios to create graphical representation of team interactions	Provided a structured way to visualize team tasks, coordination, and communication
Partial hazard and operability study (HAZOP) of two scenarios	Analyse risks in scenarios, focusing on interactions between UAM Coordinator, DUC, and stakeholders	Identified key areas for HAT improvement: situation awareness, decision-making, transparency, and communication

also led to the development of additional scenarios. The four scenarios comprise one normal and three emergency scenarios. In the normal scenario, the UAM Coordinator coordinates with ATC for a drone entering controlled airspace. In a medical emergency, the UAM Coordinator works with the air taxi operator and emergency responders, while the DUC assists with route planning and priority updates. Two safety-critical scenarios involve a fire that affects vertiports and airspace, and a link loss incident that requires coordination with the Joint Rescue Coordination Center for search and rescue.

Task analyses and operation sequence diagrams (OSD) were developed from scenarios to illustrate the temporal sequences of events, model high-level interactions and communications between system agents, and gather system requirements and specifications with a focus on interface design. A partial hazard and operability study (HAZOP) provided a structured and systematic analysis of risks in the scenarios, focussing on the interactions between the UAM Coordinator, the DUC, and external stakeholders.

Finally, the capabilities that the DUC should possess in relation to the theoretical HAT model were formulated (see Appendix A.2). These were mapped against the 34 EASA [28] Human Factor requirements and 10 Explainability technical objectives to answer whether a requirement is addressed in a conceptual definition of DUC. Subsequently, these teaming requirements were mapped against the 37 U-space services described in the CORUS-XUAM concept [2] to identify the tasks and teamwork capabilities of the actors needed for effective collaboration.

4 Work Position Proof-of-Concept Design

Following the design process described previously, we developed the proof-of-concept work position presented in this section, featuring the two key actors: the human UAM Coordinator and the DUC along with an explanation of how their teamwork is structured.

4.1 Overall Structure

The work position exists within the UCC, which manages the U-space and delivers several critical services to its users. This function has similarities with the Urban Air Traffic Management (UATM) concept proposed by Embraer and Airservices Australia [3,5,22], defined as "the collection of systems and services (including organisations, airspace structure and procedures, environment and technologies) that support the integrated operation of UAM vehicles in low-level airspace" [3] (p. 22). The UATM ConOps argue that current UTM solutions will not be able to provide services and support to UAM operations, requiring new solutions.

The UAM Coordinator works for the UCC, and is responsible for managing the U-space airspace at a higher strategic (meta) level. Rather than handling individual flights, their role focusses on airspace-wide coordination, managing exceptions, and intervening in complex or emergency situations where automation may be insufficient. In contrast, DUC will manage routine tasks such as traffic and conformance monitoring and provide flight and weather data while highlighting critical events through interface alerts. Among the U-space stakeholders, there are several secondary end-users that are subject to coordination with the UAM Coordinator and DUC. These include UAS/UAM operators, Vertiport/cargo hub operators, ATM, and emergency response organisations.

4.2 The Human: the UAM Coordinator

The UAM Coordinator has a pivotal role and responsibility in managing and coordinating U-space services, ensuring the safe and efficient flow of U-space operations. A key responsibility of the UAM Coordinator is to provide U-space services within the city and facilitate tactical human-to-human coordination between U-space stakeholders. With the support of DUC, which handles routine tasks like traffic monitoring and providing alerts, the UAM Coordinator is responsible for high-level decision making, such as resolving emergencies, managing geo-fences, and maintaining traffic priorities. While DUC manages much of the routine tasks, the UAM Coordinator remains responsible for supervising DUC and overseeing operations, responding to critical events and emergencies, and coordinating with stakeholders, including UAS/UAM operators, vertiports, cargo hubs, and emergency responders.

Although similar to ATCOs, the UAM Coordinator is foreseen to operate in a highly automated environment, where tasks like flight clearances and separation provision are largely autonomous. While routine operations may require minimal engagement, emergencies require rapid building of contextual understanding to respond effectively. The UAM Coordinator must be good at managing reactive situations, quickly building situation awareness, adapting to sudden workload changes, and communicating effectively with U-space stakeholders. Working in the multi-display workstation, supported by DUC, the UAM Coordinator can modify flight routes, address airspace constraints, and ensure seamless integration of aerial and ground operations, ensuring safety and efficiency in a highly dynamic urban airspace ecosystem.

4.3 The AI-Based System: DUC

The DUC is a conceptual AI-based system designed to function as a collaborative teammate of the UAM Coordinator. The DUC enables effective teamwork by agreeing on shared goals, developing shared situation awareness, diagnosing issues, engaging in constructive problem solving, and adapting to different contexts. The UAM Coordinator is envisioned to have partial authority over the DUC, with the DUC autonomously managing several routine tasks such as flight authorisation, flight tracking and monitoring, geo-fence monitoring, while other routine tasks are managed within defined constraints adjusted by the UAM Coordinator through the HAT interface, including conformance monitoring and conflict detection and resolution. The DUC must also be able to negotiate and execute tasks, recommend solutions such as traffic reroutings or geo-fence adjustments, and negotiate and execute tasks. Regardless of the level of authority, the DUC must be able to contribute transparently to the awareness of shared situations by providing explanations for its behaviour, actions, and recommendations. According to the AI classification of EASA, the DUC is classified as a Level 2B collaborative system [28].

In the event of unforeseen or safety-critical situations, the DUC should alert and focus the UAM Coordinator's attention, for instance, by leveraging attention-guidance functions. These situations may include emergencies and routine tasks that go beyond the DUC's decision-making authority or available information. To facilitate structured collaboration and shared situation awareness, the DUC and UAM Coordinator would rely on contingency and emergency checklists tailored to specific non-normal situations, such as passenger medical emergencies, link-loss situations, diversions, or emergency landings. This requires the DUC to detect, classify, and assess safety-threatening or non-normal events, prioritising them appropriately against other ongoing activities.

To manage U-space tasks, DUC could utilise various AI techniques, from autonomous functions (e.g., conformance monitoring and conflict detection and resolution) to shared tasks with the UAM Coordinator (e.g., checklist management, information retrieval, status reporting) and assistive capabilities (e.g., providing problem-solving recommendations). The DUC could also leverage AI techniques for collaborative purposes, including natural language processing, trajectory prediction, and attention guidance. These capabilities would allow the DUC to understand and respond to the UAM Coordinator's commands, predict traffic patterns, and guide attention for more effective collaboration.

There are several tasks that the DUC is not expected to be capable of handling. This includes human-human coordination and decision making in emergency situations, involving complex ethical judgments e.g., how to prioritise conflicting situations, coordinating with human stakeholders (e.g., air traffic management, emergency responders and healthcare services) where nuanced judgment and flexibility are required, unstructured problem solving, and handling system failures that impact airspace safety.

4.4 The Workstation

The multi-display work position features three screens and a communication system for stakeholder interaction (Fig. 1). The UAM Coordinator should be able to interact with the screens and DUC using various modalities, such as touch, mouse, and keyboard. The central screen, known as the **U-space Interface**, serves as the primary user interface for the UAM Coordinator to monitor the U-space and interact with DUC. It visualises various U-space elements, including traffic, U-plans, airspace constraints (geo-fence zones), vertiports, and landmarks. Based on the UTM City platform [29], the interface provides a 2.5-dimensional bird's-eye view of Stockholm's U-space, offering a large high-resolution display for both detailed and city-wide views. Figure 2 illustrates the

U-space interface designed for the Stockholm U-space, aligned with the European CORUS-XUAM U-space concept [2] for the 2030–2040 time frame.

Fig. 1. UAM Coordinator work position with three screens (communication system is not shown).

The screen on the left is the **Knowledge Library and Checklist display**, which provides access to manuals, checklists, and procedures for various situations. In emergency scenarios, the UAM Coordinator and the DUC can use checklists to coordinate their efforts and maintain shared situation awareness. The checklist outlines each actor's tasks, with DUC handling tasks like providing U-plan information and re-routing traffic, while the UAM Coordinator coordinates with external stakeholders to exchange information and find solutions. The DUC should be able to suggest, execute, and track the checklist steps. Similar interfaces are commonly used in various domains, including ATC, Joint Rescue Coordination Centre, and on aircraft flight decks (e.g., the electronic flight bag).

The screen on the right is the **HAT Interface** with a Digital Logbook and Explainer display. It allows the UAM Coordinator to supervise the DUC by managing teaming parameters, adjusting the DUC's automation level, allocating tasks, and modifying strategic performance settings (e.g., prioritisation rules, separation criteria). This screen integrates a digital logbook, communication log, and legal recording services, capturing all U-space actions and communications between the UAM Coordinator, DUC, and external stakeholders. The explainer functionality provides explanations for DUC's actions or recommendations, delivered in a flexible format (e.g., through storytelling with visual animations and narration). A separate screen may be needed for the explainer due to its content and interaction requirements, which would not be suitable on the U-space interface. In addition, a communication system enables the UAM

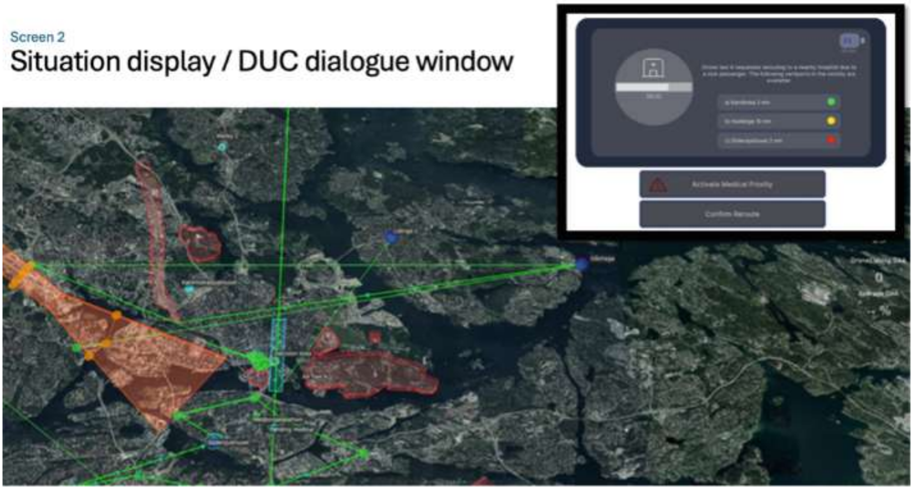

Fig. 2. Screen 2 displaying the Stockholm U-space, featuring various U-space graphical elements (e.g., vertiports, geo-fence zones, traffic) along with DUC's dialogue window.

Coordinator to connect with external stakeholders (e.g., UAS/UAM operators, vertiport operators, and emergency responders) via headset.

While DUC is embedded in all three screens, the main screen for interaction is the U-space Interface. DUC should be able to communicate with the UAM Coordinator using voice and aural alerts to provide information about changes in the U-space and notifying non-normal situations. The U-space interface facilitates communication between the UAM Coordinator and the DUC, using overlay software and dialogue windows with textual, visual, and time-based information to support decision making. The communication logic and dialogue windows are based on the continued development of the RAW concept and glyphs presented by Nylin [30]. Inspired by well-structured problems [31], DUC is required to communicate proactively with the UAM Coordinator, keeping text messages concise, informative, and easy to read. DUC should also be able to direct the UAM Coordinator's attention on the screens, using e.g., visual symbols or a "go-to" function that reorients the field of view in the U-space Interface.

4.5 Achieving Teamwork

DUC must monitor the mental state of the UAM Coordinator and factors such as workload, situation awareness, and stress using tools such as physiological sensors and eye tracking. This information is crucial to determine the timing and format of communications. The UAM Coordinator should be able to interact with DUC using different modalities, such as natural language and interface interactions using touch, mouse, and keyboard.

The UAM Coordinator and DUC collaborate on 25 high-level tasks. Among these, 23 tasks were adapted from the CORUS-XUAM U-space services concept, with two additional tasks introduced: noise and visual pollution monitoring and air situation status reporting. For example, Table 2 demonstrates the tasks and capabilities required by the DUC and the UAM Coordinator to perform the *Conformance Monitoring* service.

Table 2. Example of U-space service.

Service	Description from [2]	Task and capabilities
Conformance monitoring	Process of continuously tracking and evaluating the compliance of an aircraft to the authorised U-plan, procedures, and U-space regulations	DUC conducts the conformance monitoring service and provide alerts as necessary to the UAM Coordinator and UAS/UAM operators. The UAM Coordinator can adjust conformance monitoring thresholds and configure alerts

We anticipate that the level of engagement in task execution will differ between the actors, as shown in Fig. 3. Different screens in the UAM Coordinator's work position are used to perform different high-level tasks, as shown in Fig. 4. The orange boxes represent mainly environmental data provided by other U-space stakeholders (e.g., metrological weather institutes) that is monitored by DUC and used as input to other U-space services (e.g., traffic monitoring, dynamic capacity management, air situation status reports) and for solving problems (e.g., reroutings).

The green boxes represent tasks where both the DUC and the UAM Coordinator collaborate with varying degrees of involvement. DUC operates more autonomously for tasks such as identification, tracking, and monitoring of flights. For conflict resolution and dynamic capacity management, the UAM Coordinator should be able to set thresholds for DUC's autonomy and alerts.

Tasks like conformance monitoring, where deviations could pose safety risks, may require immediate coordination between the UAM Coordinator and external stakeholders (e.g., the UAS/UAM operator or emergency responders). Other tasks, such as geo-awareness and vertiport services, may also require human coordination. For example, the UAM Coordinator should be able to implement geo-fence zones on short notice. Lastly, services related to legal recording aspects (i.e., capturing and recording of what happens in the U-space) will involve both the UAM Coordinator and DUC. Although DUC is expected to monitor and record most activities, the UAM Coordinator must oversee, edit, and supplement information as needed. Crucially, the UAM Coordinator will use the Air Situation Status Report to trigger U-space adjustments, such as modifying capacity or changing constraints and thresholds that guide DUC operations. Legal recording also plays a key role in fostering shared awareness and ensuring transparency between both actors.

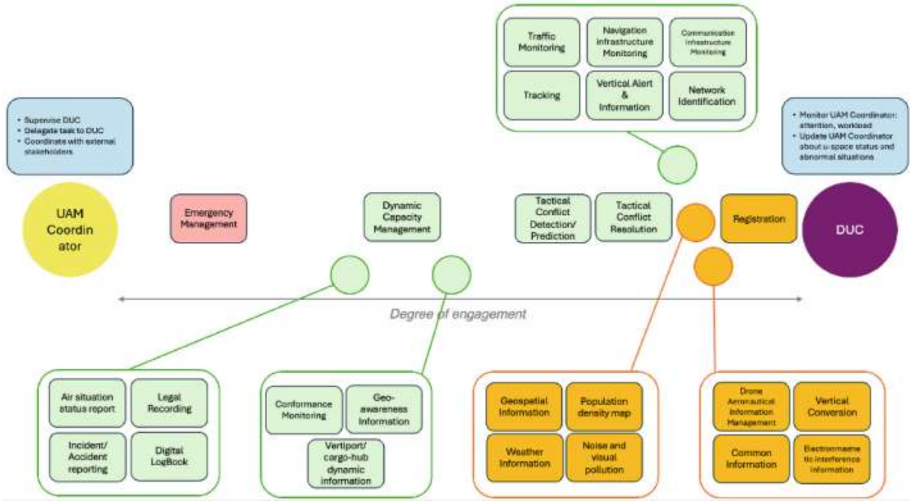

Fig. 3. UAM Coordinator and DUC engagement in identified high-level tasks.

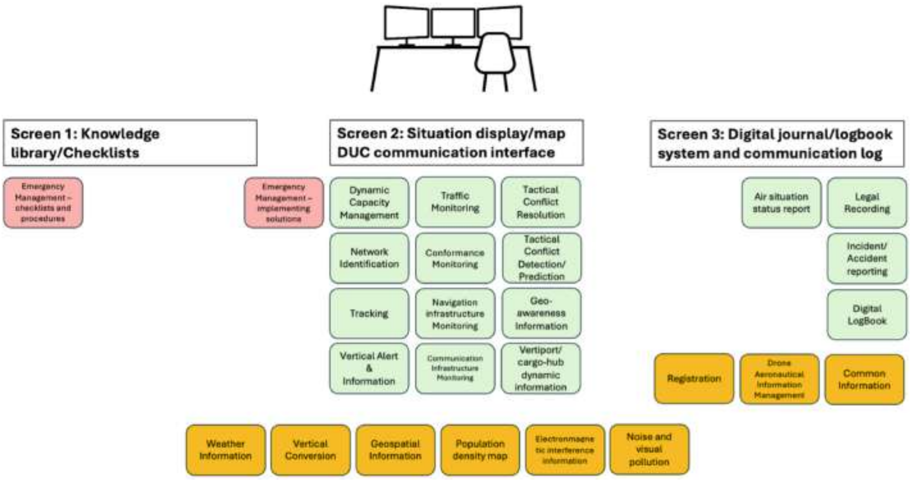

Fig. 4. High-level tasks distributed across screens in the UAM Coordinator working position.

Emergency management is a critical task that is primarily handled by the UAM Coordinator, with DUC providing support through a structured checklist to ensure efficient task division and shared situation awareness. It is the UAM Coordinator's responsibility to assist UAS/UAM operators in emergencies (e.g., activate contingency plans and find solutions), communicate with relevant parties (who may be affected or can help), and ensure compliance with emergency procedures like configuring safety boundaries and adjusting flight priorities. This process is expected to require extensive human-human coordination with other stakeholders, such as emergency responders and UAS/UAM operators.

The DUC could help highlight critical situations in the U-space interface, visualising dynamic elements such as U-plans and traffic hotspots, retrieving flight and contingency information, and proposing risk reduction measures. Both the UAM Coordinator and the DUC would be required to maintain a continuous listening watch on emergency channels, similar to 121.5 MHz in aviation.

5 Conclusion

Multiple studies and reports indicate that UAS traffic cannot be managed using traditional ATM methods. The scale of operations, increased aircraft movements, and involvement of new stakeholders necessitate higher levels of automation and a dedicated coordination function. We propose that this role can be effectively fulfilled by the UAM Coordinator, supported by the AI-based system DUC. This paper presents their shared working environment, implemented as a proof-of-concept work position design. The conceptual design enables exploration of the dynamics of HAT in the management of U-space traffic in various concrete scenarios, providing stakeholders with insights into its feasibility, challenges, and potential opportunities. Through iterative testing, including workshops and human-in-the-loop simulations with ATCOs and domain experts, the research identified key teamwork dynamics, task allocation strategies, and critical challenges such as maintaining human oversight, ensuring trust in automation, and balancing AI autonomy with human decision-making. These findings contribute to the broader understanding of how HAT can be structured to support safe and efficient operations in safety-critical environments, with a particular focus on U-space operations in complex urban airspaces.

To be truly effective in HAT, an AI-based intelligent assistant must be carefully designed to genuinely support users, rather than adding to their administrative burden. Achieving viable U-space operations requires appropriate automation and seamless system integration to create an efficient working environment for human operators. Establishing the UAM Coordinator function can facilitate the transition from traditional ATM-based operations to a highly autonomous and mature U-space system. The value of the UAM Coordinator in mature U-space operations will depend on the evolution of automation, with a fully automated ecosystem anticipated in the long term. However, we believe that a human supervisor will remain essential for handling unforeseen events and emergencies that exceed the capabilities of autonomous systems. The UAM Coordinator work position concept introduces several innovative aspects that require further exploration. Unlike traditional ATM roles, there is no established reference for this position, making it a novel approach to U-space operations. Key areas of research include identifying relevant data sources to support the coordinator, defining the necessary skills and training for operators, and determining how traffic flow should be structured in urban airspace. Furthermore, it is crucial to delineate the responsibilities best suited for human operators versus those that can be effectively managed by AI systems. Finally, the development of advanced tools to improve HAT and optimise collaborative decision making remains a critical area for future work.

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A Appendix

A.1 Glossary

Terminology Used in this Article
AAM = Advanced Air Mobility. Refers to innovative and disruptive airborne technology to transport people and goods to areas beyond the reach of traditional air transport, including complex and rural urban environments [1].
Air Taxi = aircraft with or without pilot on board that carries passengers [2].
CIS = The Common Information Service distributes data to support the provision of U-space services [2].
CORUS-XUAM = European U-space concept of operations developed as part of a European Horizon 2020 funded project [2].
Drone = aircraft without an on-board pilot, also known as UAS [2].
Emergency Responders = organisations that handle emergency operations, including fire brigades, medical services, and Search and Rescue teams [2].
Geo-fence zone = a defined airspace volume with operational requirements or constraints that can restrict access to aircraft. If no operations are allowed, it is referred to as a no-fly zone.
UAM = Urban Air Mobility. Refers to aircraft-based means of transportation near or within cities [2].
UAM Operations = air operations above urban areas, in U-space airspace, carried out by a mix of aircraft with limited range and unable to fly visual or instrument flight rules, which require tactical separation [2].
UAS = Uncrewed/Unmanned Aerial System. Aircraft that can carry passengers but is usually piloted remotely or autonomously [2].
UTM = UAS Traffic Management. An ecosystem for traffic management of UAS operations [2].
U-space airspace = the airspace that contains the UAS and UAM operations [2].
U-space services = European system to manage UAS and UAM operations [2].
U-plan = flight plan in U-space airspace [2].
UAM Control Centre (UCC) = the office of the UAM Coordinator and the DUC.
Vertiport = similar to conventional airports, these are dedicated ground-based

facilities that support the take-off and landing of aircraft, including UAS and piloted aircraft such as VTOL and helicopters.
VTOL = Aircraft capable of Vertical Take-OFF and Landing [2].

Roles Referred to in this Article
DUC = Digital Assistant for the UAM Coordinator. A conceptual AI-based intelligent assistant that collaborates with the UAM Coordinator to manage the U-space and provide U-space services.
UAM Coordinator = human actor responsible for the tactical management of the U-space and the provision of U-space services.
UAM Operator = legal entity that operates and is responsible for one or more UAM flights that carry passengers or goods [2].
UAS Operator = legal entity that operates and is responsible for one or more UAS flights [2].
U-space Service Provider (USSP) = stakeholder providing U-space services [2].
Vertiport Operator = entity that manages and provides vertiport services, including accommodating incoming aircraft [2].

A.2 DUC HAT Requirements

Situation Awareness

- DUC should be able to continuously monitor the U-space and traffic operations, providing real-time updates and alerts to the UAM Coordinator.
- DUC should be able to monitor the U-space by collecting real-time data from multiple sources, including data from aircraft and weather.
- DUC should be able to process the incoming data to identify trends and detect anomalies.
- DUC should be able to generate status reports on U-space operations, incidents, and performance metrics.
- DUC should be able to detect potential conflicts between UAS/UAM vehicles, such as near-collisions or airspace violations.
- DUC should be able to perform simulations and scenario planning to anticipate future traffic patterns and potential U-space capacity issues.
- DUC should be able to retrieve and present information on the request of the UAM Coordinator.
- DUC should be able to infer what information the UAM Coordinator needs and present it.
- DUC should be able to call for/direct the UAM Coordinator's attention to important information (e.g., attention guidance).

Transparency

- DUC should be able to provide explanations on request.
- DUC should be able to correctly determine and understand what the UAM Coordinator is trying to understand, for which an explanation is needed.
- DUC should be able to demonstrate the relevance of an explanation for a decision/action.
- DUC should be able to determine an appropriate level of abstraction of an explanation according to the task, situation, trust, and expertise of the UAM Coordinator.
- DUC should be able to explain how it derived an output.
- DUC should be able to explain how it works.

Bidirectional Communication

- DUC should be able to provide indication of having acknowledged the UAM Coordinators' instructions/intentions.
- DUC should be able to understand and generate human natural language.
- DUC should be able to communicate using different modalities, including voice, text, and graphics (e.g., highlight areas on the map).
- DUC should be able to not interfere when the UAM Coordinator is involved in other communications or actions.
- DUC should be able to automatically adapt the modality of interactions to end-user states, preferences, and situations

Decision Making

- DUC should be able to recommend actions/solutions.
- DUC should be able to decide and implement actions within its performance envelope.
- The DUC should allow the UAM Coordinator to adjust some of the authority limits and constraints in decision making and action implementation.
- DUC should be able to identify poor and suboptimal strategies/actions/solutions proposed by the UAM Coordinator.
- DUC should be able to propose and justify optimised solutions, where applicable.
- DUC should be able to propose alternative strategies/actions/solutions.
- DUC should be able to solve problems with the UAM Coordinator following a checklist.

References

1. National Academies of Sciences, Engineering, and Medicine: Advancing Aerial Mobility: A national blueprint. The National Academies Press, Washington, DC (2020). https://doi.org/10.17226/25646

2. EUROCONTROL.: U-space ConOps and architecture (edition 4). CORUS-XUAM Technical report (2023). https://www.sesarju.eu/node/4544. Accessed 20 Apr 2024
3. Airservices Australia and Embraer Business Innovation Center: Urban Air Traffic Management. Concept of Operations. Version 1 (2020). https://engage.airservicesaustralia.com/urban-air-traffic-management-concept-of-operations. Accessed 20 Apr 2024
4. EASA: Study on the societal acceptance of Urban Air Mobility in Europe (2021). https://www.easa.europa.eu/sites/default/files/dfu/uam-full-report.pdf. Accessed 10 Jan 2025
5. EVE Air Mobility: Urban air mobility concept of operations for the London environment (2022). https://www.eveairmobility.com/uk-consortium-completes-urban-air-mobility-concept-of-operations-for-the-civil-aviation-authority/. Accessed 12 June 2024
6. Lyons, J.B., Sycara, K., Lewis, M., Capiola, A.: Human-autonomy teaming: definitions, debates, and directions. Front. Psychol. **12**(589585) (2021). https://doi.org/10.3389/fpsyg.2021.589585
7. National Academies of Sciences, Engineering, and Medicine: Human-AI Teaming: State-of-the-Art and Research Needs. The National Academies Press, Washington, DC (2022). https://doi.org/10.17226/26355
8. Endsley, M.R.: Supporting human-AI teams: transparency, explainability, and situation awareness. Comput. Hum. Behav. **140**, 107574 (2023). https://doi.org/10.1016/j.chb.2022.107574
9. O'Neill, T., McNeese, N., Barron, A., Schelble, B.: Human-autonomy teaming: a review and analysis of the empirical literature. Hum. Factors **64**(5), 904–938 (2022). https://doi.org/10.1177/0018720820960865
10. EASA: Artificial Intelligence Roadmap 2.0. Human-centric approach to AI in aviation (2020). https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-roadmap-20. Accessed 10 Jan 2025
11. Westin, C., Borst, C., Hilburn, B.: Automation transparency and personalized decision support: air traffic controller interaction with a resolution advisory system. IFAC-PapersOnLine **49**(19), 201–206 (2016). https://doi.org/10.1016/j.ifacol.2016.10.520
12. Chen, J.Y.C., Barnes, M.J.: Human-agent teaming for multirobot control: a review of human factors issues. IEEE Trans. Hum.-Mach. Syst. **44**(1), 13–29 (2014). https://doi.org/10.1109/THMS.2013.2293535
13. Schaefer, K.E., Straub, E.R., Chen, J., Putney, J., Evans, A.W.: Communicating intent to develop shared situation awareness and engender trust in human-agent teams. Cogn. Syst. Res. **46**, 26–39 (2017). https://doi.org/10.1016/j.cogsys.2017.02.002
14. Battiste, V., Lachter, J., Brandt, S., Alvarez, A., Strybel, T.Z., Vu, K.-P.L.: Human-automation teaming: lessons learned and future directions. In: Yamamoto, S., Mori, H. (eds.) HIMI 2018. LNCS, vol. 10905, pp. 479–493. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-92046-7_40
15. McNeese, N.J., Demir, M., Cooke, N.J., Myers, C.: Teaming with a synthetic teammate: insights into human-autonomy teaming. Hum. Factors **60**(2), 262–273 (2018). https://doi.org/10.1177/0018720817743223
16. Westin, C., Boonsong, S., Josefsson B., Lundberg, J.: Building trust in autonomous system competence - the DiTA digital tower assistant for multiple remote towers, an early concept evaluation. In: 39th AIAA/IEEE DASC, San Antonio, TX, USA, pp. 1–9 (2020). https://doi.org/10.1109/DASC50938.2020.9256759

17. Lundin Palmerius, K., Henriksson, M., Westin, C., Lundberg, J.: Digital tower assistant functionality and design: planning, analysis and operative interfaces based on workshops with ATCOs. In: 12th SID, Budapest, Hungary (2022)
18. Jameel, M., Tyburzy, L., Gerdes, I., Pick, A., Hunger, R., Christoffels, L.: Enabling digital air traffic controller assistant through human-autonomy teaming design. In: 42nd IEEE/AIAA DASC, Barcelona, Spain, pp. 1–9 (2023). https://doi.org/10.1109/DASC58513.2023.10311220
19. Lundberg, J., Johansson, B.: A framework for describing interaction between human operators and autonomous, automated, and manual control systems. Cogn. Technol. Work **23**, 381–401 (2021). https://doi.org/10.1007/s10111-020-00637-w
20. Nylin, M., Westberg, J.J., Lundberg, J.: Reduced autonomy workspace (raw)-an interaction design approach for human-automation cooperation. Cogn. Technol. Work. **24**(2), 261–273 (2022). https://doi.org/10.1007/s10111-022-00695-2
21. Endsley, M.R.: Toward a theory of situation awareness in dynamic systems. Hum. Factors **37**(1), 32–64 (1995). https://doi.org/10.1518/001872095779049543
22. EVE Air Mobility: Concept of Operations for sustainable urban air mobility in Rio De Janeiro. Brazil (2022). https://eveairmobility.com/wp-content/uploads/2022/05/EveConopsRJ.pdf. Accessed 12 June 2024
23. FAA: Unmanned Aircraft System (UAS) Traffic Management (UTM) Concept of Operations v2.0. Federal Aviation Administration, Washington (2020)
24. Boeing: Concept of Operations for Uncrewed Urban Air Mobility (2022). https://www.boeing.com/content/dam/boeing/boeingdotcom/innovation/con-ops/docs/Concept-of-Operations-for-Uncrewed-Urban-Air-Mobility.pdf. Accessed 19 Apr 2024
25. FOCA: Swiss U-Space ConOps. Swiss Federal Office of Civil Aviation (FOCA) (2020)
26. Goodrich, K.H., Theodore, C.R.: Description of the NASA urban air mobility maturity level (UML) scale. In: AIAA Scitech Forum. Virtual Event (2021). https://doi.org/10.2514/6.2021-1627
27. Levitt, I., Phojanamongkolkij, N., Horn, A., Witzberger, K.: UAM airspace research roadmap rev 2.0. NASA/TM-20230002647. NASA Langley Research Center, Hampton (2023)
28. EASA: EASA Artificial Intelligence (AI) Concept Paper Issue 2: Guidance for Level 1&2 machine learning applications (2024). https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-concept-paper-issue-2. Accessed 10 Jan 2025
29. Westberg, J.J., Palmerius, K.L., Lundberg, J.: UTM city-visualization of unmanned aerial vehicles. IEEE Comput. Graph. Appl. **42**(5), 84–89 (2022). https://doi.org/10.1109/MCG.2022.3193160
30. Nylin, M., Lundberg, J., Bång, M., Kucher, K.: Glyph design for communication initiation in real-time human-automation collaboration. Vis. Inform. **8**(4), 23–35 (2024). https://doi.org/10.1016/j.visinf.2024.09.006
31. Simon, H.A.: The structure of ill-structured problems. Artif. Intell. **4**(3), 181–201 (1973). https://doi.org/10.1016/0004-3702(73)90011-8