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AN OPERATIONAL CONCEPT FOR THE INTEGRATION OF URBAN AIR MOBILITY VEHICLES INTO THE AIR TRAFFIC CONTROL PROCESSES

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Abstract

Urban Air Mobility (UAM) is one of the future transportation concepts. Intense research and development activities are performed worldwide to foster a rapid implementation. In addition to developing vehicle desings and route networks, procedures to integrate these new airspace users into existing airspace structures are required. Most UAM operations are intended to take place in separate airspace which is controlled by a designated Urban Air Traffic Control. However, for the common use case as airport shuttles, interaction with conventional Air Traffic Control becomes inevitable. This paper presents a generic operational concept to facilitate the integration of UAM vehicles into the Air Traffic Control processes, applied on the example of Hamburg Airport. In accordance with a previously designed route network, a suitable Take-off and Landing site at the airport was identified. Based on the selected location and the resulting dependencies with conventional traffic, procedures for controllers were created. Since strong increases in workload are hypothesized due to the addition of UAM operations, an enhanced radar display was developed to assist the controllers. The procedures as well as the display views were evaluated for their feasibility by air traffic controllers.

Keywords: airport, air taxi, air traffic control, air traffic management, urban air mobility, urban air traffic management

1. Introduction

The road traffic density in urban areas has increased within the past years [6, 3]. This development requires new transportation concepts to reduce travel delays. Among others, Urban Air Mobility is presented as one solution to this issue by providing on-demand individual and affordable air transportation for passengers and goods [8, 14]. A prerequisite for the operation of UAM vehicles is the safe integration into the existing airspace with its current structure and procedures. For this purpose, various research institutes and government agencies such as the National Aeronautics and Space Administration (NASA) or Airservices Australia have provided proposals for Concept of Operations (CONOPS) for Unmanned Aircraft System Traffic Management (UTM) [2, 8, 13]. The different approaches all have in common that they foresee the number of vehicles rising and the level of automation increasing over time. Initial operations might be performed within the current Air Traffic Management (ATM) system [2]. The rapid increase in controller workload when integrating even small numbers of UAM vehicles into controlled airspace has impressively been demonstrated by initial Human in the Loop (HIL) simulations performed by Airservices Australia [2]. Hence, with the expected quick increasing number of UAM vehicles airborne, a mostly independent UTM system needs to be developed [2, 13] to keep the operations, especially from an Air Traffic Control (ATC) perspective, safe and scalable [23].
Regardless of the implementation and time frame of such an independent UTM system, it will be necessary to include ATC in the process as soon as an UTM operation enters a control zone - at least in initial stages with limited automation.
Therefore, this paper aims at presenting a process for those use cases where interaction between ATC and UAM pilots become inevitable. One of the most discussed UAM operations for which this

Figure 1 – Selected UAM route network (own figure, based on [1], used with permission)

applies, is shuttle service to and from airports [2, 22] which will be targeted by the concept introduced here.

The challenge of integrating air taxis into airport operations is multi-fold. First, these are vehicles whose flight performance strongly differs from conventional fixed wing traffic. The prediction of critical situations between airspace users has therefore to be performed very carefully. Second, the majority or even the entity of the airport shuttle operations takes place in the control zone of the airport and therefore in the responsibility of the controller. Due to the limited range of air taxis, extended holding patterns in case of ongoing fixed-wing operations at the airport are not feasible. Thus, their operations should take place continuously once started which needs an exact planning of their trajectory. Third, UAM operations will be performed at low-level altitudes [8] and as such in the areas with the highest abundance of birds [9] as well as drones [17]. Due to the reduced certification specifications on impact resistance [11], UAM vehicles will have to perform evasive maneuvers to avoid damage due to bird or drone strikes regularly. This will lead to rescheduling of arrival times of air taxis vehicles at the airport and therefore increase the controller workload to integrate them into the existing procedures.

Initial HIL simulations by Airservices Australia [2] have revealed rapid increases in workload when expanding the tower controller's task to monitor and guide UAM traffic as well. The study concludes that, among others, dedicated corridors, a high predictability of UAM traffic and new procedures are vital to achieve a feasible integration. Therefore, a feasible and resilient operational concept is required. The here proposed CONOPS take these requirements into account. In addition, the controller tools are enhanced with additional information to further reduce workload while improving situational awareness. The resulting CONOPS and tool design were evaluated by five air traffic controllers and their feedback used for fine-tuning these elements.

2. Method

The goal of this study was to design CONOPS to integrate UAM operations into air traffic controller procedures. Therefore, a generic controller workflow based on requirements from existing and foreseen regulations was developed and applied for the example of Hamburg airport. The resulting CONOPS are based on a route network and three Touch-down and Lift-Off (TLOF) locations proposed in a previous study [1]. In a first step, the most suitable TLOF in terms of controller feasibility was identified in a discussion with five ATM experts. Second, controller procedures considering the TLOF and route specifications were developed. Third, controller support tools were designed for this use case and, after an evaluation by five controllers, enhanced.

2.1 Route Network and TLOF location

A previous study [1] proposed the route network for shuttle transportation to and from Hamburg airport. The routes, which will be applied within the here described CONOPS, are shown in Figure 1.

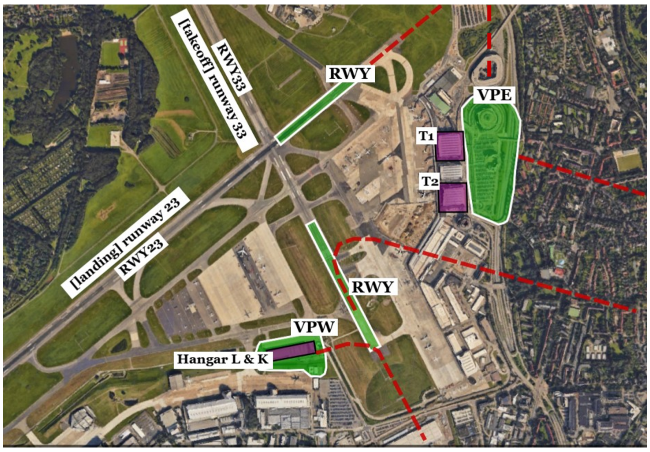


Figure 2 – Potential TLOF locations. RWY: Runway; VPW: Vertiport West; VPE: Vertiport East (source: [1], used with permission).

That study also had identified three potential on-site TLOF locations at Hamburg airport. Within the here presented work, the performance of each TLOF location was assessed with regard to each category of the *Expectations for the global ATM system* as defined by the International Civil Aviation Organization (ICAO) [16]. Based on the results, the operational feasibility of the location was evaluated and the one most suitable for actual implementation identified. The three options for TLOF locations are shown in Figure 2 and briefly described below. A more detailed description can be found in [1].

The location *Runway (RWY)* entirely relies on the current infrastructure. In accordance with the main operational directions of conventional air traffic, air taxis depart from runway 33 and arrive on runway 23. Hence, conventional and UAM traffic operations are dependent of each other and have to be fully coordinated.

The TLOF location *Vertiport West (VPW)* is on the air side of the airport, just west of the head of runway 33, in place of hangars K and L. The operation of this TLOF is dependent on the runway operations twofold. First, subsiding jet blast from aircraft departing from runway 33 has to be awaited to maintain safety. Second, the UAM flight routes cross the runways.

The TLOF location *Vertiport East (VPE)* is on the land side of the airport, on top of the car park east of the terminal buildings. Independent operations of UAM traffic can be performed if the angle between their flight paths to the runway center lines amounts to a minimum of 15° [12]. Therefore, the UTM route from the south-east (cf. Figure 2) is independent from conventional traffic. In contrast, the direct route from Quickborn in the North is dependent due to its crossing of the arrival path of runway 23.

In a workshop with five ATM experts (1 female, 4 male), the characteristics of each of the potential TLOF locations was discussed for all categories. Their expertise covers the ATM research areas of airport operations, capacity and safety studies as well as their validation in real- and fast-time simulations. After the initial discussion, each of the participants individually rated their performance for the different categories and identified the TLOF location to be selected to base the CONOPS upon.

To evaluate the different TLOF visualized in Figure 2 with regard to the ICAO ATM requirements, their performance per category was first captured in a descriptive manner in a workshop with five ATM experts. Thereafter, the participants individually weighted the importance on a scale from 0-10 with regard to the context of this study. Additionally, they each rated the performance of the three TLOF locations for each category, again on a scale from 0-10. The products of the rating and weighting per category were summed to obtain the total rating per participant.

2.2 Air Traffic Control Procedure

At least in initial stages of UAM, it is to be expected that air taxis entering the control zone of an airport will need to communicate with ATC to comply with current regulations as well as Instrument

Flight Rules (IFR) and flow management procedures.
Hence, controller workload is expected to increase due to this additional traffic. Additional factors which increase the complexity are the expected on-demand nature of UAM [22], the different performance characteristics of air taxis as well as their operation at altitudes used by Visual Flight Rules (VFR) flights and frequented by birds and drones.
The developed process aims at minimizing additional controller workload while maintaining the safety standards and complying with current regulations. It is designed in a generic manner to be applicable at any airport and will be explained on the selected example of Hamburg airport to demonstrate its applicability.

2.3 Controller Assistance

To accommodate the additional controller workload and to maintain situational awareness, an enhanced ground radar display was designed. The additional items include information about active UAM routes, as well as current and predicted bird and drone activity based on avian and drone radar information. In addition, flight strips for air taxis traffic were developed. The basic principle was to present the UAM information in the same way as the other traffic data. Anyhow, controllers should be aware that the controlled flight is a UAM to judge its performance. Therefore additional coloring was necessary. Moreover, a special marking is required to inform the controller about entry and exit points of the UAM as these do not follow published IFR or VFR routes.

2.4 Evaluation Workshops

The designs for the enhanced radar displays were evaluated by five tower air traffic controllers. In addition, they were questioned about their impression on the feasibility of the developed workflow. Since the goal of the workshops was to obtain initial qualitative feedback, this sample size was considered as sufficient.
All of the air traffic controllers were trained as tower and apron controllers of Vienna airport. They were all males of an average age of 30 years (SD = 3.74) and a work experience of 5.8 years (SD = 3.43). Based on their feedback, the elements of the displays and the procedures were refined.
The controllers each participated in an individual online-workshop of about two hours. They first were provided with an introduction to the topic of UAM integration and bird/drone strike prevention. Second, the display elements and the controller procedures were outlined. Third, the controllers were presented screen recordings to demonstrate the working of the display designs. Fourth, the controllers were asked to fill in two online questionnaires to provide their feedback. The workshop was completed by an open discussion to capture additional remarks.
The first questionnaire considered the display elements regarding the visualization of bird and drone strike risk. The second one focused on the display of UAM traffic.
Both questionnaires included ratings on the usability and the acceptability of the displays. These were collected by capturing the degree of agreement to different statements on Likert scales [18].
Display usability was determined with the System Usability Scale (SUS) [4]. The SUS includes ten statements to be rated on a five-point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree). Since no interaction took place within the workshop, the statement "I felt very confident using the system" was replaced by "I would feel very confident using the system". The ratings were translated to point values (1=least favourable to 5=most favourable) and an SUS score computed. Thereby, the maximum score of 100 referred to the maximum number of possible points, i.e. 50 (ten statements with a maximum ranking of five).
Display acceptability was measured twofold. First, the overall acceptability was rated from one ("Very unacceptable. I did not like the display and would not use it") to five ("Very acceptable. I like the display very much and would use it without any improvements"). Second, the Technology Acceptance Scale (TAS) [7] with its sub-scales usefulness and satisfiability was applied. Regarding usability, six statements were ranked from one ('extremely unlikely') to seven ('extremely likely'). In the context of satisfiability, nine statements were ranked into five categories from 'useless' to 'useful' and translated to values from one to five. For all ratings, higher scores indicate better results.
In the subsequent part of the questionnaire included free-text questions regarding advantages, disadvantages, ideas for improvement as well as feedback on design of individual display elements.

After filling in each questionnaire, the displays and the procedures were discussed to gather additional feedback and thoughts which might not have been captured by the questionnaires. Here, a special focus lay on the overall procedure for handling UAM traffic.

After the evaluation of the controllers' responses, the initial designs of the displays and procedures were refined. Their final structure will be described in the results section.

3. Results

This section describes the individual components of the CONOPS developed in this work. First, the selection of the TLOF location and the resulting dependencies of the route network are described. This is followed by an overview of the ATC workflow and the display designs to support the controllers in its performance. After the presentation of the controller feedback on these setups, the performed updates to achieve the final configurations are described.

3.1 TLOF Location

For the selection of the TLOF location, the ratings of their performance with regard to the ICAO ATM requirements were considered. The final rating is the product of the weighting per category (cf. Table 1) and the points assigned per location and category.

Table 2 summarizes the resulting performances of the three TLOF locations. It can be seen that, even though the points assigned by the individual participants differ, they all ranked the three TLOF locations identically. Therefore, the TLOF location VPE was selected to base the Air Traffic Controller (ATCO) workflow upon. That TLOF is on the landside of the airport. The direct air taxi route from the North (cf. Figures 1 and 2) is dependent from IFR traffic since it crosses the final approach part of runway 23. The other routes are independent.

3.2 Air Traffic Control Workflow

German law defines six common services for ATC organisations. These are air traffic services, communication services, navigation services, flight surveillance, flight information and weather services. [5]. Out of these, especially the air traffic services which include Air Traffic Flow Management (ATFM) and control services are impacted by air taxis operations due to the mentioned dependencies [1]. For conventional ATFM, tower control publishes the airport capacity according to weather conditions, staffing and multiple other issues. Based on the resulting capacity, the traffic flow to the airport is adapted by the network management. In terms of air taxis, this mechanism is not applicable as these are not intended to be part of the conventional network management (e.g. [13]). Moreover, the network manager's slot system to adapt the flows is not designed for the typical short travel times of air taxis. For the defined use case of Hamburg, most air taxi routes have a flight time of approximately 15 to 20 minutes [22], as can be expected for typical inner-city operations [1]. As the slot system allows deviations of minus five to plus 10 minutes [10], it is not accurate enough to prevent congestion induced by air taxis. Hence, an additional mechanism must be introduced which allows tower control to delay air taxis once congestion of the airspace or an overload of the controller is expected. Beside ATFM, tower control is mainly responsible for the so-called control service which includes flight guidance for IFR and monitoring of IFR and VFR flights. Both tasks ATFM and traffic control are impacted by air taxi operations as their planning and execution is assumed to differ from the one of conventional traffic. In the case of IFR flights, the operators file flight plans indicating, among others, the desired route prior to operation [1]. During the flight, the aircraft follows published routes in the air and on the ground as as advised from the ATCO to the pilot . If controllers detect a deviation to the given advisories, they assess the situation, contact the pilot via voice communication, and repeat or adapt the advisories provided.

The integration of air taxis into controlled airspace provides an additional task for ATC. To keep these operations scaleable from a controller's point of view [23], the interaction with air taxi pilots should be stronlgy limited. According to current regulations (cf. e.g. [5]), also non-IFR traffic has to request clearance to enter an airport's control zone. In case of air taxi shuttles to the airport, it is expected that

[1] In case of traffic under visual flight rules, a flight plan might not be necessary, but the pilot will inform about the desired route upon initial call.

Table 1 – Median and average weighting of importance of the ICAO categories

Category	**median**	**average**
Access and Equity	3.6	2
Capacity	7.6	9
Cost-effectiveness	5.2	6
Efficiency	7	7
Environment	6.4	8
Flexibility	5.4	6
Global Interoperability	1	0
Participation by the ATM community	1	0
Predictability	4.2	4
Safety	9	9
Security	6.4	8

Table 2 – Rating of TLOF performance by participant

Category	**RWY**	**VPW**	**VPE**
Participant I	51	83	115
Participant II	200	454	572
Participant III	249	433	468
Participant IV	280	358	417
Participant V	273	402	459
median	**249**	**402**	**459**
average	**210.6**	**346**	**406**

already the take-off will take place within the control zone and has therefore be approved by ATC. Due to their limited range, air taxis will not be able to perform extensive holding procedures in case of en-route conflicts with IFR traffic. Hence, they either need prioritization or, alternatively, their trajectory needs to be planned precisely in advance to avoid potential interactions. In-flight replannings of the trajectory by the air taxis, for example due to wind influence or avoidance maneuvers of drones or birds, may strongly influence the controller's workload.

Summarizing the impact on ATFM, trajectory planning and execution, three major steps are identified required to successfully accomplish an air taxi flight. The steps as well as the contained tasks are shown in Figure 3 and described below.

Taking into account the requirements identified in [2], air taxis are using individual routes and mechanisms to increase the predictability of their operations are included.

In line with the general aim of UAM to provide individual and flexible transportation (e.g. [22]), air taxis are assumed to operate on an on-demand basis. Therefore, the first step *Operations Planning* is initiated by the a future passenger requesting a flight. This flight request is proceeded by the UAM operator. As soon as the flight plan foresees the flight to enter the Terminal Maneuvering Area (TMA), to land or depart from an airport, it the request has to be forwarded to ATC for a capacity check. In the selected use case of Hamburg, all routes lie within the control zone and start or end at

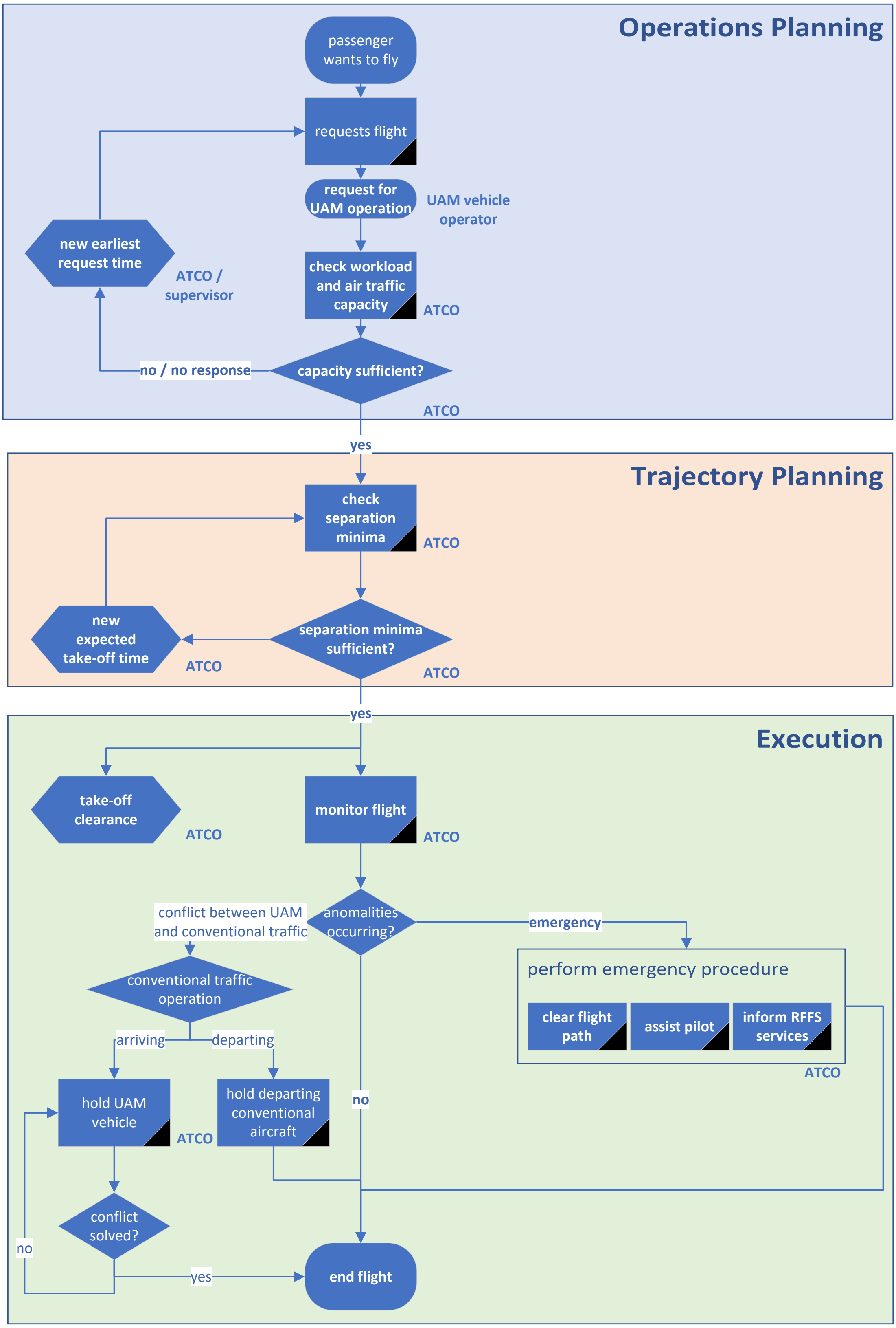


Figure 3 – ATCO workflow

the airport. ATC will either approve the flight or, in case of constrained airport capacity or controller workload, suggest a new departure time. By following this first step of the workflow, an efficient ATFM is ensured. While ATFM only has a focus on traffic numbers, the next step of detailed *Trajectory Planning* contains checks of conflicting points with other air taxis or conventional traffic. This step is performed by the responsible tower controllers. They need to assess whether separation minima to air taxis already airborne as well as IFR traffic are violated by the air taxi trajectory provided by the UAM operator. If the trajectory does not comply with the separation minima, a new takeoff time for the air taxi will be suggested as a pragmatic, one-dimensional, time separation mechanism. For future application this step can be enhanced by a 4D optimization of the air taxi trajectory, adapting flight route and altitude.

Once a trajectory which ensures the separation minima is agreed on, tower control will announce the takeoff clearance and the flight can be conducted.This initializes the third step of *Execution*. As soon as the flight enters the TMA, the tower controller is responsible for monitoring the flight. If deviations from the agreed trajectory occur, the controller has to assess the cause and apply different priority schemes to solve potential conflicts.

If an air taxi experiences an emergency situation, its safe guidance to the ground has priority. The controller therefore has to follow the standard procedures to clear the concerned area, assist the pilot and alert the Rescue and Fire Fighting Service (RFFS).

In case of a non-emergency conflict with conventional traffic, the following prioritization takes place. According to the basic rules of ATC of "safe, order and expeditious" flight guidance, departing conventional traffic has to be hold back at the airport to enable the air taxi to complete its flight. This is the safest situation for all airspace users. In case of arriving IFR traffic, the conventional traffic has priority to avoid costly go-arounds which would result in detours of more than 20 NM. In contrast, the air taxi can hold its position by circling or even hovering within a radius of less than one nautical mile. However, the limited battery range of air taxis could lead to the necessity of an unplanned landing outside of the airport environment or a go-around of a conventional aircraft which should both be avoided. This emphasizes the importance of the second phase of *Trajectory Planning*. Once the air taxi continuous its flight to its destination and touches down, the phase of flight execution is closed and the responsibility of ATC finished.

3.3 Supporting Tools

Tower control is based on multiple supporting tools for the ATCO in charge. In general, five basic tools are state of the art:

- The radio and telephone system allows the controller to communicate with pilots, airport staff and other controllers.
- The flightstrips provide information (e.g. estimated times, callsign, aircraft type, requested route) on each flightplan.
- The airside / ground situational display shows aircraft position based in radar data to enforce situational awareness of the controller.
- The weather information system displays wind and temperature information to enable decisions on runway operations.
- The capacity HMI which is provided by the European network management to assess and regulate the traffic flow.

Airports which operate under high traffic volumes use additional supporting systems such pre-departure sequence to support the controllers in improving the traffic flow.

As the HIL simulations in [2] demonstrated, controller workload rises quickly when integrating UAM operations without providing additional support. Hence, changes in the operational concept should be reflected within the provided supporting tools. Following the above presented concept for UAM operations, the controller must have the opportunity to approve or disapprove an UAM movement (step *Operations planning*). Within the second step of *Trajectory Planning*, sufficient information to assess separation minima and to induce take-off delays for air taxis must be provided. For the *Execution*, a possibility to issue clearances and movement advisories as well as a communication to the air taxi operator must be established. It is hypothesized that the adaption of supporting tools contributes to the controllers situational awareness and reduces the additional workload to a feasible level.

The controllers should be provided with the five basic supporting tools described above. In order to achieve the intended situational awareness increase and workload reduction, adaptations to the flight strips and the radar display are performed.

First, air taxis will be represented by flight strips, including their intended route as well as their Estimated Time of Arrival (ETA) at the airport. The flight strip is interactive in the sense that the controller can reschedule the take-off time which will automatically be transferred to the UAM operator.

The major changes involve the radar display. They include elements for air taxi operations as well as uncooperative airspace users.

3.3.1 Air Taxi Operations

Air taxis spend up to 20 minutes flight time in the control zone and thus under controller supervision. Especially for air taxis to the airport, it is relevant to the controller to be aware of air taxis currently airborne and on their ETAs at the airport.

Therefore, air taxi routes are displayed in black. In case of active traffic on one of the routes, its color changes from black to purple. In addition, a label with the ETA at the TLOF will be shown. Departing traffic will be labelled with a Calculated Take Off Time (CTOT). As soon as the air taxi completed its journey, the label disappears and the route changes its color back to black. In case of en-route replanning, the relevant times are updated. If an uncooperative airspace user (see below) is predicted to cross an active route, the route is highlighted until the uncooperative airspace user passed it.

3.3.2 Uncooperative Airspace Users

An initial HIL study by the Federal Aviation Administration (FAA) [15] indicated that tower controllers appreciate notifications of bird movement in order to raise situational awareness and to prevent potential bird strikes. Due to birds flying at low altitudes, conventional IFR traffic is mainly exposed during take-off and landing. In contrast, air taxis will fly in bird abundant heights throughout their entire operation. In addition, drone traffic, which takes place at similar heights, is increasing. Hence, air taxis are expected to experience more collisions with such uncooperative airspace users. To enhance aviation and aviation safety, the use of modern technology to track and predict their flight paths and to display potential risks to the controllers, should be embraced [19, 20]. The introduction of additional visualizations is intended to enhance situational awareness as proposed by [15] and to increase aviation safety for air taxis as well as IFR traffic.The required movement information as well as target type and size can be obtained from avian and drone radar. Track propagation is predicted based on a system as proposed by [21].

To display the uncooperative airspace users, their predicted position within the next 30 seconds is displayed. To account for uncertainties in prediction, their potential location is visualized by the shape of a two-dimensional cone. Its length depends on the target's current speed, its width on the certainty of prediction. The color of the cone encodes the expected potential for damage. The visualization is reduced to uncooperative airspace users where, based on the type and its size, a medium or high potential for damage (severity) is expected and the track can be predicted up to a certain extent. High severity is coded with dark red, medium severity with dark orange. Cones are displayed with a transparency of 50 % to reduce conspicuity. Tracks with medium predictability are visualized by a cone of 25 degrees opening, for highly predictable tracks, 10 degrees are applied.

In order not to distract the controller with too detailed information, only the cone and its propagation based on radar updates is displayed. More insight can be gained on demand by clicking on the cone. This triggers the visualisation of the target's trajectory up to the current point as well as a label. The label contains the information about the target type (bird or drone), the certainty of the track prediction, the expected severity of the impact, the height as well as the current speed of the target.

These initial designs for the radar display enhancement was presented to the five controllers for evaluation and feedback. In addition, they were questioned about their impression of the intended controller workflow. The final designs including suggestions by controllers are described subsequently to the results of the evaluation workshops.

3.4 Evaluation Workshops and Final Display Designs

Within the evaluation workshops, five controllers rated the display elements for air taxi operations and uncooperative airspace users with regard to acceptance and usability. Since the individual rankings have different scales, they were all adapted to a range from 0-100 for comparability. The results are displayed in Table 3. Out of the eight rankings, six achieved values higher than 80 %, with all categories reaching values higher than 70 % for both display elements.
The named advantages, disadvantages and suggestions for potential improvement as well as the resulting changes in the display set-up are described below.

Table 3 – Average controller ratings on acceptability and usability for the UAM and uncooperative airspace user additions in the radar display, in percentages

Category	**Air taxi operations**	**Uncooperative airspace users**
Acceptance - Overall	88 (SD = 9.8)	72 (SD = 16)
Acceptance - Usefulness	78 (SD = 23)	86 (SD = 19)
Acceptance - Satisfiability	89 (SD = 15)	86 (SD = 20)
Useability - SUS	88 (SD = 4)	81 (SD = 14)

3.4.1 Air Taxi Operations

All controllers appreciated the highlighting of active routes to maintain situational awareness of airborne air taxis and described the selected color as pleasing. To reduce complexity, it was suggested by one controller to only highlight the parts of the routes still ahead of the air taxi. The display of planning times was described as useful. For those, two controllers suggested countdowns instead of clock times while the other three confirmed usefulness of this measure when asked about it.
The highlighting of air taxi routes in case of predicted crossing uncooperative traffic was appreciated to immediately discover potential threats. However, two controllers pointed out a danger of visual overload in case of high traffic densities.
Concluding from these suggestions, the adaptations shown in Table 4. Figure 4 shows the final setup for these elements. In case of a replanning and therefore change to the countdown to the ETA, the surrounding rectangle briefly blinks to notify the controller about the update. The color of active routes is purple (RGB-Values (102, 000, 153)) and the highlighting in case of crossing uncooperative airspace users takes place in their respective cone color.

Table 4 – Adaptations of air taxi operations visualization

Topic	Initial	Final
Active Route	entire route is highlighted	route segments ahead of airborne air taxis are highlighted
Planning Times	displayed in clock time	displayed as countdown in minutes
Uncooperative Airspace Users	highlighting of route if crossing anywhere on route	highlighting of route in case of crossing ahead of and at similar altitude of air taxi

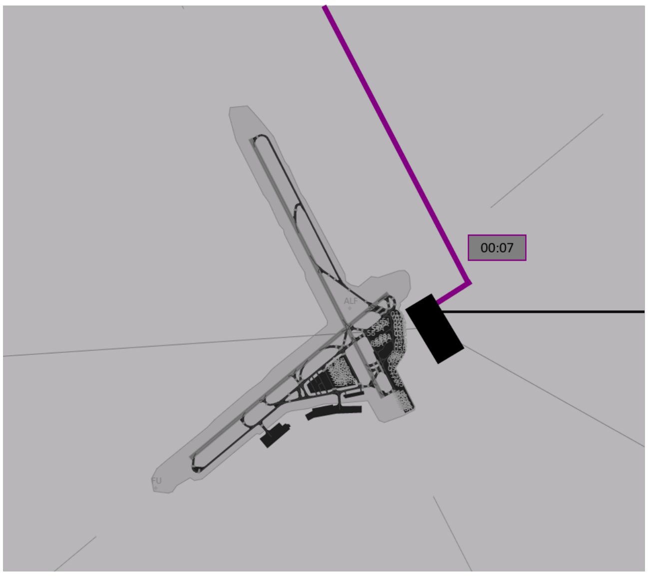
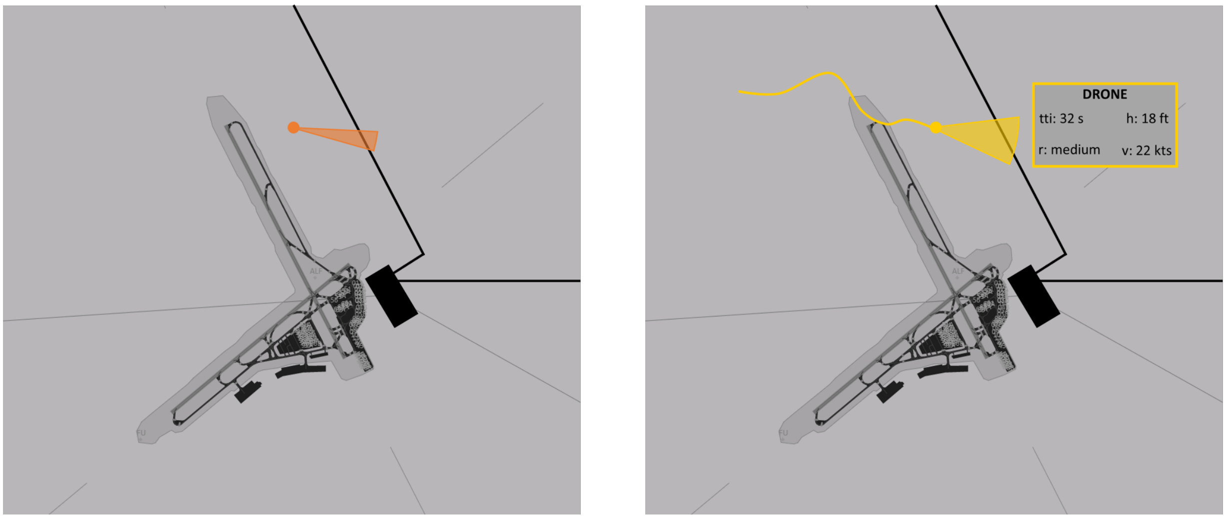


Figure 4 – Radar display with information of current air taxi traffic. Purple line: route actively in use. Black line: alternative UAM route, currently not in use. Black rectangle: vertiport. Grey rectangle: countdown in minutes to ETA

3.4.2 Uncooperative Airspace Users

Also the display elements for the visualization of uncooperative airspace users received high rankings for acceptance and useability (cf. Table 3). Controllers saw the main advantage in immediate recognition of strike risk for conventional aircraft and for air taxi. They valued the simple visualization which was perceived as intuitive. Moreover, they appreciated that only the cone was visible continuously and extra information would only show on request. There was mixed feedback regarding the color choice. Two controllers favoured the selection of dark red for high and dark orange for medium threat. Three controllers found these colors too alerting, especially in contrast to the threat of e.g a runway incursion. Improvements were proposed in the visualization of the current bird position and by adding a time when the runway or the air taxi route are expected to be clear of uncooperative traffic. In addition, alternative or additional information for the label were suggested. Filtering of birds/drones to be displayed was evaluated differently. While one controller even would wish to see low-risk targets, others would prefer to see only those with a clear direction towards an active runway or air taxi route. One controller would have favoured seeing at least the three radar positions of the target all the time. One controller showed a clear preference for an indication whether the runway is safe to operate or not rather than an addition to the radar display while one suggested such a simplified solution as an alternative option.

Based on the controllers' responses, some of the display elements were adjusted as Table 5 shows. Figure 5 displays the final setup. Figure 5a shows the elements which are always present on the radar display. Figure 5b includes the extra information which can be obtained by clicking on the cone.



(a) Display of simplified information (target with high certainty of trajectory prediction and high damage potential)

(b) Display with additional content upon request of the controller (target with medium certainty of trajectory prediction and medium damage potential

Figure 5 – Radar display enhanced with information about uncooperative airspace users

Table 5 – Adaptations of uncooperative airspace user visualization (ht: high threat; mt: medium threat)

Topic	Initial	Final
Current Position	peak of cone	dot on peak of cone
Label Elements	type (bird/drone), probability, severity, height, velocity	type (individual bird / flock /drone), time to intersect, risk, height, velocity
Cone Color	ht: dark red (RGB (153, 0, 0)); mt: dark orange (RGB (237,125,49))	ht: dark orange (RGB (237,125,49)); mt: dark yellow (RGB (255,204,0))

3.4.3 Feedback on Controller Workflow

The controllers agree that the introduction of air taxi traffic would strongly increase their workload. Clear procedures on how to include them in the traffic flow would be inevitable. A critical element is the prediction of workload. According to two controllers, predicting their workload and the exact IFR traffic flow for the next twenty to thirty minutes is almost impossible. Hence, planning a trajectory without any conflicts to IFR traffic would be highly challenging. Therefore, prioritization rules between IFR and air taxi traffic have to be defined well prior to operations. Another prerequisite was seen in a strict regulation for air taxis regarding with regard to their adherence to routes and flight heights to keep the additional operations feasible.
With regard of warnings of uncooperative airspace users, two controllers would advise IFR traffic to delay take-off in case of a predicted strike. Two controllers would provide an information to the pilots and leave them to decide about a take-off delay. One controller would differentiate between high (advisory) and medium (information) risk for his decision. Considering air taxis, one controller would prefer advisories, while the others would only forward the risk information. One controller stated that he would do so with limited priority in comparison to IFR traffic. Also in the context of bird/drone

strike prevention, the controllers mentioned the need for clear procedures in order to remove legal responsibility.

4. Discussion and Conclusions

The implementation of air taxi operations will face multiple challenges among which this paper addressed the integration into controlled airspace and interaction between controllers and pilots. Especially in the initial stage of UAM, this interaction will be inevitable once air taxis enter the control zone of an airport as required for the common use case of shuttle services.
Due to their specific characteristics of on-demand operations as well as strongly limited range, air taxis will need special consideration when including them into the workflow of controllers.
This paper proposed CONOPS for the operation of air taxis from the controller's perspective. Therefore, a controller workflow as well as enhanced radar displays were developed and applied to a previously proposed route network as well as a here selected TLOF location at Hamburg airport. Out of three locations, five ATM experts clearly favoured the solution of a land site TLOF, the VPE. The lowest dependencies from conventional traffic mainly influenced this choice. In addition, reduced security protocols might be required since the air taxis will not access the air side of the airport. In contrast, passengers would need to undergo a security screening in case of connecting flights. The selection took place by rating the potential TLOF locations against the *Expectations for the global ATM system* by ICAO. This method provides a pragmatic option for an initial evaluation and can be recommended for further use at different airports.
The controller workflow developed within this work is kept on a high level and can therefore be adjusted for individual airport or airspace characteristics. This paper demonstrated how the workflow can be specified. As controller feedback suggested, it is vital to clearly define individual work steps and the responsibility of the controller. Thereby, decisions which address prioritization between air taxis and IFR traffic have to be performed by a superior level, limiting the task of the controller to its execution.
The expected high number of air taxi traffic in the future as well as their individual characteristics and the strongly increased risk for collision with uncooperative airspace users, it is expected to strongly increase controller workload. Hence additional tool support is seen as required. This paper proposes the addition of extra flight strips as well as an enhancement of the ground radar display. Elements for the visualization of air taxi routes as well as their intended arrival and departure times were developed. In addition, elements to display uncooperative airspace users and their risk for air taxi as well as conventional traffic, were designed. Controller feedback on the design was mostly positive. Main concerns included an overload of the display in case of high number of air traffic and/or uncooperative airspace users. Therefore, the highlighting of active air taxi routes is limited to the part still ahead of the air taxi. Additional highlighting of routes predicted to be crossed by uncooperative airspace users is reduced. These highlighting only take place, if a collision is likely to occur. Additional minor improvements such as a clearer indication of the current position of uncooperative targets and the replacement of planned departure/arrival times with countdowns were implemented. Having in mind that the number of controllers is limited, only room for improvement indicated by a majority was considered.
Based on the favourable feedback of the controllers of the intended set-up for the CONOPS, a next step is to validate their elements in HIL simulations. Thereby, the workflows will be evaluated in (simulated) operations and the hypothesis of the necessity of additional controller assistance tested.

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Copyright Statement

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