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Extending air traffic control tasks to control air taxis and to warn of critical wildlife: an impact analysis

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Abstract
Despite large and successful efforts to keep wildlife off airports, many collisions between aircraft and animals still happen at low altitudes outside the airport boundaries, where wildlife is most abundant. These wildlife strikes are especially threatening for aircraft departing from airports as well as for envisioned low-flying urban air mobility aircraft. The here presented study evaluates the operational feasibility of a concept to provide tower air traffic controllers with wildlife strike risk information to contribute in a reduction of these critical strikes. For this purpose, real-time human-in-the-loop simulations with ten air traffic controllers were performed in a 360° tower simulator. Based on controller feedback as well as measures for safety and efficiency, the findings indicate feasibility of providing controllers with wildlife strike risk information. It is expected that the refinement of the procedures presented here will pave the way towards field-tests and eventually actual implementation of air traffic control involvement in wildlife strike prevention.

Keywords Air taxis · Air traffic control · Efficiency · Safety · Urban air mobility · Wildlife strike prevention

Abbreviations

ATC	Air traffic control
ATCO	Air traffic controller
eVTOL	Electrical vertical take-off and landing
FAA	Federal Aviation Administration
HIL	Human-in-the-loop
ISA	Instantaneous self-assessment
UAM	Urban air mobility
WCU	Wildlife control unit

1 Introduction

Collisions with wildlife and in particular with birds have caused loss of life and aircraft since the beginning of powered aviation [1]. With the highest wildlife abundance up to about 3000 ft, operations of large commercial aircraft are mostly exposed during take-off, initial climb, approach and landing, while their cruise phase takes place at much higher and thus non-critical altitudes [2]. In contrast, general aviation aircraft, rotorcraft and envisioned electrical vertical take-off and landing (eVTOL) vehicles typically spend their entire flight time at low altitudes where wildlife is most present [3, 4]. With reduced impact resistance requirements [5], these aircraft types are not only exposed throughout their entire operations but also highly endangered to suffer damage when colliding with wildlife.

Hence, when developing concepts for airspace integration of air taxi services performed by eVTOL aircraft within the future urban air mobility (UAM) framework (e.g., [3, 6, 7]), additional measures to reduce the likelihood of wildlife strikes are vital [8].

Including the operators—pilots and air traffic controllers (ATCOs)—in the process as proposed previously in fixed-wing context ([2, 9, 10]) is, therefore, seen of even higher relevance in the UAM context. Many air taxi operations will take place in control zones around cities and/or airports and thus have to be supervised by air traffic control (ATC) [11, 12]. By presenting ATCOs with wildlife strike risk information, they can dedicatedly warn pilots of specific threats and thus increase avian and aviation safety [2, 10, 13]. On the other hand, extending their tasks to the monitoring of additional airspace users—air taxis and wildlife—may impact their workload and situation awareness and thus their performance in their other tasks. To assess the magnitude of these potential effects, real-time human-in-the-loop (HIL) simulations including ten ATCOs were performed.

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An operational concept to integrate UAM traffic within the tower control processes was developed in Metz and Schier-Morgenthal [14]. While Schier-Morgenthal and Metz [15] evaluated the addition of UAM traffic to tower control processes, this study accounts for the increased wildlife strike risk for UAM traffic, providing controllers with respective information.

A 2017 study by the Federal Aviation Administration (FAA) [9] revealed ATCO appreciation for receiving wildlife movement information in the tower working environment. Moreover, the study suggested that this measure could even decrease ATCO workload. Therefore, the operational concept encompasses the use of visualizations of UAM routes and risky wildlife within the controller's airside situation display. It was assessed by five ATCOs and revised based on their feedback prior to integrating it into the real-time simulations [14].

The main goal of the here presented study was to analyze the effects on safety, represented by workload and situation awareness, as well as efficiency when including ATCOs in the wildlife strike prevention process. In addition, preferred strategies for treating wildlife strike risk information were evaluated.

To assess potential consequences on the safe and efficient handling of traffic flow, three conditions were evaluated. First, ATCOs were to control air taxis within a standard working position and without any wildlife activity. In the second condition, information about wildlife activity around the airport was provided orally from the airport's Wildlife Control Unit (WCU). The airside situation display was enhanced by visualizing all UAM routes, highlighting active ones. In the third condition, wildlife strike risk information was additionally provided on the airside situation display for better situation awareness regarding UAM traffic location and facilitated identification of potential wildlife-UAM conflicts. It was hypothesized that especially in the third condition, ATCOs would be able to integrate the control of air taxis and warnings about wildlife strike risk without negative impact on their situation awareness or workload.

2 Methods

This section provides an overview of the simulation setup, the experimental conditions, the airside situation display enhancements to provide wildlife strike risk and UAM traffic information, the participants and the metrics which were applied to investigate the goals of the study.

2.1 Simulation setup

The study was performed in the 360º Apron- and Tower Simulator of the German Aerospace Center's Institute of Flight Guidance. The simulator is equipped with 13 projectors, and provides a 360º outside view [16]. The simulation design is based on a fast-time simulation study evaluating the integration of air taxi services to the control zone of Hamburg [17]. On dedicated routes, air taxis perform shuttle services between nine vertiport locations in the extended city environment and the airport of Hamburg-Fuhlsbüttel (EDDH). The vertiport at EDDH is located on landside, south-east of the intersecting runways 23 for arrivals and 33 for departures. It operates independently of runway traffic, except when ATCOs provide air taxis arriving from the North a shortcut which intersects the final approach path of runway 23 (cf. [14, 17]). Figure 1 presents an overview of the simulated airspace.

In the automated fast-time simulations, adding up to 20 air taxi movements in a peak hour with a maximum of 44 conventional aircraft movements at the airport proved feasible when simulated in fast-time [17]. To transfer the scenario to HIL simulations, a concept on how to include air taxi flows in the ATCO workflow was developed [14]. To account for human interactions not considered in the fast-time simulations, the number of air taxis was reduced to 15 per hour for the HIL-experiments.

2.2 Experimental conditions

For this study, the following conditions were created to analyze the influence of wildlife presence and respective ATCO information on the safety and efficiency of operations:

a)Conventional fixed-wing and UAM traffic with conventional ATC tools (CONV) and no wildlife (NO-WL) present: **CONV_NO-WL.**
b)Conventional fixed-wing, UAM traffic and oral information about wildlife activity with conventional ATC tools: **CONV_WL-OR.**
c)Conventional fixed-wing, UAM traffic and information about wildlife activity with conventional ATC tools and the enhanced airside situation display **ENH_WL-VS.**

Every controller participated in simulations for all conditions in the same order with each simulation run lasting 1 h.

Previous to the simulation runs, all ATCOs received a briefing about the simulated procedures at EDDH in general and regarding the UAM traffic. Concerning wildlife, the ATCOs were advised to use the presented information up to their discretion, to avoid implying any bias in developing wildlife strike mitigation strategies. All ATCOs received a training in condition CONV_NO-WL, with a different traffic than in the trial. The duration of the training run lasted a minimum of 30 min and could be extended to 1 h on request.

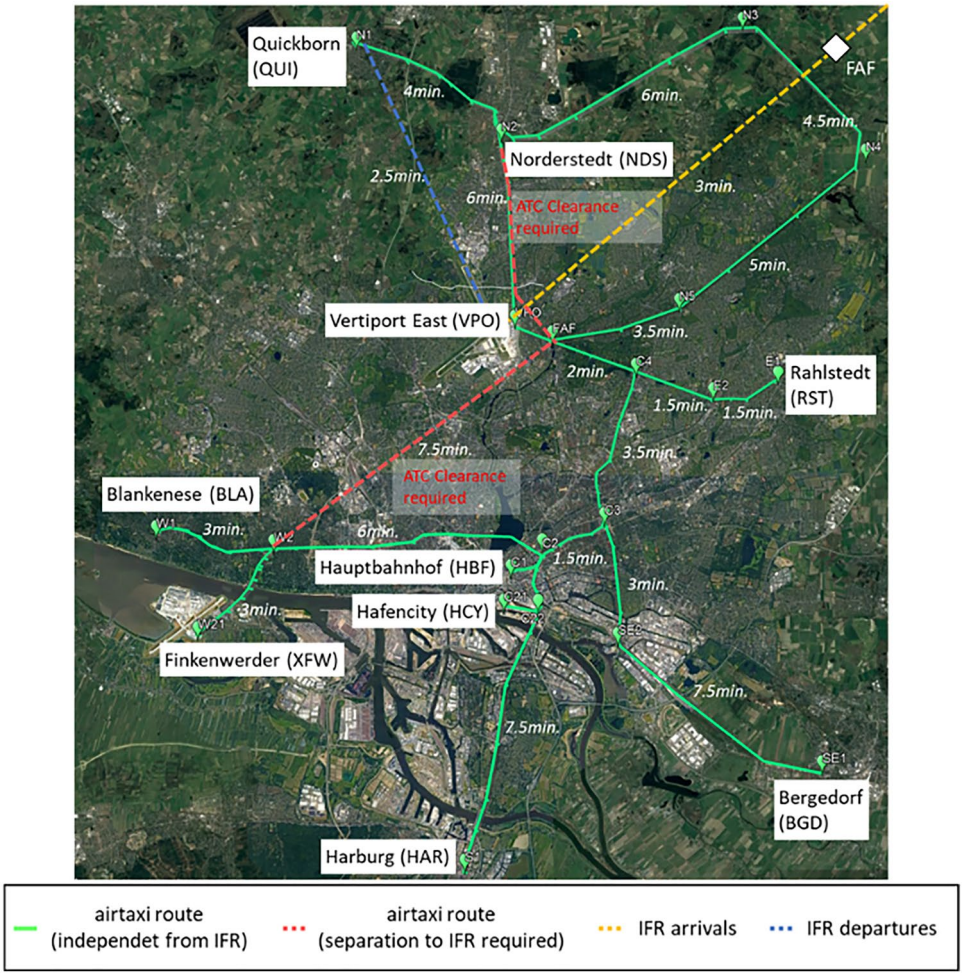

Fig. 1 Overview of the simulated airspace

The training and the simulation run of condition CONV_NO-WL took place on the 1st day of the trials. The experimental conditions CONV_WL-OR and ENH_WL-VS were simulated on the 2nd day. In between, different conditions including UAM traffic but no wildlife for a partnering study [15] were simulated. To reduce training effect from individual simulation runs, two versions of the resulting traffic scenario with random shifts in flight order were used.

By comparing conditions CONV_NO-WL and CONV_WL-OR, the impact on safety in terms of ATCO workload and situation awareness when controllers receive oral wildlife strike information was assessed. Thereby, information on wildlife strike risk was transmitted orally from the WCU, as would be operationally possible today. Since the complete range of UAM routes is beyond a feasible observational area of WCU, information was provided for wildlife movement in the direct airport environment only.

In condition ENH_WL-VS, a more advanced setting was assumed. There, the airside situation display showed critical wildlife movements in the entire control zone, assuming surveillance coverage for its entire expansion. Consequently, by comparing conditions CONV_WL-OR and ENH-WL-VS, the value of the enhanced airside situation display to handle potential wildlife conflicts was analyzed.

In both conditions including wildlife risk information, ATCOs were instructed to use the strike risk information to their discretion. This allowed to exploratory assess their preferences and development of strategies to integrate this information into their workflows.

In conditions CONV_WL-OR and ENH-WL-VS, four air taxis and four departing conventional fixed-wing aircraft were scheduled to encounter wildlife activity. This high number of events within 1 h of simulation time was required to obtain meaningful results. Since the ATCOs expected such events to happen, an increased alertness has to be expected and considered when analyzing the results of the study.

Two of the air taxis experienced a near miss in each of the conditions. Their simulation pilots were briefed to hover for about 60 s to let the wildlife pass and to avoid a collision, if

informed by the ATCO. The other two air taxis collided with wildlife in any case. Their simulation pilots were briefed to perform an emergency landing, once at an alternate airport and once on the departure runway at EDDH. Since the air taxi take-off triggered the wildlife activity with the en-route part of air taxi flights happening without human interaction, these encounters were guaranteed to happen as intended.

In case of conventional departing aircraft, three crossings of flocks of the extended runway center line and one occurrence of lingering birds at the Northern end of the runway took place conditions CONV_WL-OR and ENH-WL-VS. To give ATCOs a chance to react to wildlife movement, the visualization was triggered between one and two minutes prior to reaching the runway holding point. The simulation pilots were briefed to request a departure delay if the controllers informed about wildlife activity. Depending on the current traffic flow and ATCO or simulation pilot reaction times, it was subject to chance whether a departing aircraft would actually collide with wildlife, if the ATCO did not intervene.

2.3 Hypotheses

It was hypothesized that introducing wildlife risk information without additional assistance in condition CONV-WL_OR, workload would slightly increase, while situation awareness as well as the efficiency parameters would slightly decrease in condition CONV_WL-OR. When providing the controllers with visual support in condition ENH_WL-VS, the parameters were expected to return to comparable ranges of condition CONV_NO-WL. Table 1 provides an overview of all hypothesized changes.

With regard to taxi times, the following dependencies between departure delays of fixed-wing aircraft imposed to prevent wildlife strikes (conditions CONV-WL-OR and ENH-WL-VS) exist. Outbound taxi times, defined as delta between actual off-block and take-off time, increased due to the delay. In contrast, inbound taxi time, defined as delta between actual landing and actual in-block time as recorded by the simulator, was assumed to reduce since the delaying of departures led to additional opportunities to cross the departure runway.

The second efficiency parameter is air taxi flight duration. ATCOs only had to manually ensure air taxi separation between the EDDH vertiport and the merging fix of all routes. While en-route, the air taxis performed self-separation. For the routes to the North and to the West, ATCOs could assign two shortcuts, substantially decreasing flight times. However, due to dependence of the runway system, the usage of the shortcuts requires increased monitoring by the ATCO (cf [15, 17].). Hence, it was hypothesized that increasing workload would result in less shortcuts provided. Furthermore, delays in clearances and additional holdings over the merging fix were expected, all leading to higher air taxi flight times. To avoid bias, only the flight duration of air taxis that was not affected by wildlife was included in this part of the analysis.

2.4 Working positions

The participants were connected via radio to three simulation pilots who performed the aircraft movements according to the ATCOs' advisories. The first simulation pilot controlled conventional departures, the second conventional arrivals and the third one steered the air taxis. The ATCO working position included the airside situation display, a flight strip display and a weather display in all conditions (cf. Fig. 2). The enhancements of the airside situation display for condition ENH_WL-VS are described in the next section.

Table 1 Overview of hypotheses

Parameter		CONV_NO-WL VS CONV_WL-OR	CONV_WL-OR VS ENH_WL-VS	CONV_NO-WL VS ENH_WL-VS
Safety	Workload	CONV_NO-WL < CONV_WL-OR	CONV_WL-OR > ENH_WL-VS	CONV_NO-WL = ENH_WL-VS
	situation awareness	CONV_NO-WL > CONV_WL-OR	CONV_WL-OR < ENH_WL-VS	CONV_NO-WL = ENH_WL-VS
Efficiency	taxi-in Times	CONV_NO-WL < CONV_WL-OR	CONV_WL-OR > ENH_WL-VS	CONV_NO-WL = ENH_WL-VS
	taxi-out times	CONV_NO-WL > CONV_WL-OR	CONV_WL-OR < ENH_WL-VS	CONV_NO-WL = ENH_WL-VS
	flight duration air taxis	CONV_NO-WL < CONV_WL-OR	CONV_WL-OR > ENH_WL-VS	CONV_NO-WL = ENH_WL-VS
	Throughput	CONV_NO-WL > CONV_WL-OR	CONV_WL-OR < ENH_WL-VS	CONV_NO-WL = ENH_WL-VS

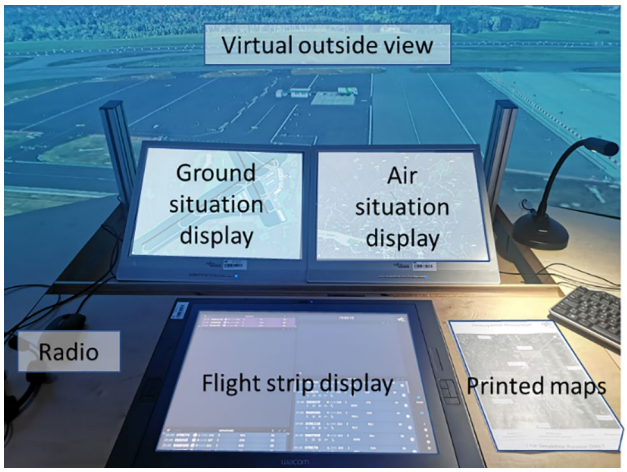

Fig. 2 ATCO working position

2.5 Enhanced display acceptability and usability

ATCOs are surrounded by much information presented both visually as orally. Any additional information bears the danger of disproportionately increasing workload and lowering situation awareness [18, 19]. Therefore, UAM traffic and strike risk information was visualized within the existing airside situation display. Thereby, the proposal for the display described in Metz and Schier-Morgenthal [14] was slightly modified after ATCO feedback and testing in real-time simulations to further accommodate operational requirements.

2.5.1 Wildlife strike risk information

Risk is defined as product of likelihood and severity of a predicted event [20]. In the context of this study, risk is referred to the predictability and severity of a collision between an aircraft and wildlife.

For the purpose of this study, the implementation of a system to predict propagation of wildlife movement from avian radar recordings [13] was assumed to be installed. Since avian radars provide categorization of size and flocking of wildlife [10], a severity assessment and consequently a risk evaluation was included in the system logic. The ATCOs were presented with the visualization of the system's output. The current wildlife position was indicated with a dot, the possible position of the next 30 s with a cone. Thereby, the width of the cone indicated the certainty of prediction while its color represented the expected severity of impact in case of collision. To reduce the number of wildlife visualizations and thus avoid overloading the display, only targets with a minimum predictability and severity were displayed. These are labeled as medium or high, for which Table 2 contains the cone specifications. A detailed description of the visualization can be found in Metz and Schier-Morgenthal [14].

Table 2 Cone specifications for wildlife targets

Category	Probability (cone width)	Severity (color)
Medium	25°	Dark yellow (255, 204, 0)
High	10°	Dark orange (237, 125, 49)

In addition to this basic representation, ATCOs could display the previous part of the track as well as a label with additional information by clicking on the cone. This on-request mechanism served the reduction of elements constantly present on the screen. Figure 3 shows a wildlife target with all information available. In the example, a target with high predictability and severity is displayed. The label information shows an individual flyer which is expected to intersect an aircraft's trajectory in 92 s at 1134 ft, poses a high risk and flies with a speed of 45 kts.

2.5.2 UAM routes

In conditions CONV_NO-WL and CONV_WL-OR, only the waypoints of the UAM routes were visible on the radar screen. In condition ENH_WL-VS, the routes were marked with grey lines (RGB (144, 144, 144)) between the waypoints. The parts of active routes yet to be traveled by UAM traffic were highlighted in purple (RGB (102, 000, 153)). In the present study, this highlighting of routes is an integral part of the radar display enhancement. It intends to enhance situation awareness regarding UAM traffic location and to facilitate the identification of potential wildlife-UAM conflicts. Wildlife cones overlapping active UAM routes and as such indicate an immediate threat cause the affected route segment to be highlighted in the color of the wildlife target.

2.6 Participants

Ten ATCOs (2 female, 8 male, average age 35.1 years, SD 7.2 years) participated in the simulation trial. They all were from airports other than Hamburg and held licenses for tower control ($n=5$), combined tower/apron control licenses ($n=2$) and apron licenses ($n=3$).

The average operational experience of the participants was 9.6 years (SD = 6.8 years). Two of the ATCOs had participated in the initial display evaluation described in Metz and Schier-Morgenthal [14].

The range of educational background implies a wide range of experience from different working conditions. This is beneficial since it might lead to a wider range of strategies

Fig. 3 Wildlife target with expanded extra information on the airside situation display

to deal with the presented wildlife strike information. However, with regard to efficiency and workload, there might be increased variation between ATCOs. This has to be considered when analyzing the objective performance metrics.

2.7 Evaluation parameters

The main objectives of ATC services are safety and efficiency [21]. Therefore, these parameters were assessed within the simulation to test the hypotheses that ATCOs can include wildlife strike risk information and warnings into their workflow without impairing their performance. Thereby, situation awareness and mental workload represented the indicators for safety, while throughput of flight movements, flight duration of air taxis and taxi times of conventional aircraft served as measures for efficiency.

2.7.1 Safety—workload and situation awareness

For the assessment of mental workload during the simulation, the Instantaneous Self-Assessment (ISA) measure [22] was applied. ATCOs were asked to provide a rating from one to five (1 = under-utilized; 2 = relaxed; 3 = comfortable, 4 = high, 5 = excessive) on a pop-up window every 5 min during each simulation run.

To evaluate situation awareness as well as the connection to mental workload within the simulation trials, the Situation Awareness for Solutions for Human Automation Partnerships in European Air Traffic Management (SASHA) questionnaire [23] was presented to controllers after every simulation run. The questionnaire includes six questions addressing the aspects information extraction, integration of anticipation to be answered on a 7-point Likert scale (never to always). Combining the values by averaging across the six sub-groups results in an overall assessment of situation awareness.

2.7.2 Efficiency

Workload and situation awareness can impact the controller's traffic handling. Owning sufficient mental capacities, the controller will be able to give commands in time and provide an optimal traffic flow. To evaluate impacts in this study, runway throughput, taxi times and take-off delays for conventional fixed-wing traffic and flight time of air taxis were assessed for the three conditions.

Runway throughput was calculated by first counting the number of landings and departures per 5-min interval. The throughput for every condition was then determined by calculating the average of all five-minute intervals of all controllers per condition. For air taxis, the landings and departures at any vertiport were considered.

To calculate air taxi flight times, the period between take-off and touchdown of all air taxi aircraft per condition were cumulated and averaged over the number of air taxis present

in that run. Only the air taxis not affected by wildlife were included to avoid bias due to hovering times or shortened routes because of emergency landings.

In contrast to air taxis, conventional air traffic is only controlled by the tower ATCO during take-off and landing. In the selected simulation setup of EDDH, arriving aircraft need to cross the departure runway which is also overseen by the ATCO. To evaluate potential delays in handling of conventional traffic, average taxi time to and from the gate was calculated per condition.

2.8 Enhanced display acceptability and usability

In condition ENH_WL-VS, an enhanced radar display to visualize wildlife strike risk was introduced. Its usability and acceptability were assessed in questionnaires after the simulation of that condition to evaluate display usability, and the System Usability Scale (SUS) [24] was used. To assess display acceptability, the Technology Acceptance Scale (TAS) with the sub-scales of usefulness and satisfiability [25] was used. To compare the display performance since its upgrade after the initial study [14], the questionnaires were set up and evaluated identically as in that study. The resulting scores lie within a range between 0 and 100. To translate them into levels of agreement about acceptability and usability, the rating scale defined for SUS in Bangor et al. [24] was applied for both, TAS and SUS. As such, scores above 70% are to be considered as favorable.

The post-run questionnaire also included free-text fields for the ATCOs to provide feedback to the visualization of wildlife strike risk, the highlighting of UAM routes, information desired to be displayed and how the ATCOs prefer to use information in their daily operations.

2.9 Use of wildlife strike risk information

The post-run questionnaire included open questions on how to best use wildlife strike risk information. Moreover, ATCOs were invited to provide feedback in the debriefing after the final simulation run.

3 Results

To evaluate the effects of the introduction of wildlife strike risk information in a scenario with conventional and UAM traffic, the various measures were compared between the three conditions CONV_NO-WL without the consideration of wildlife, CONV_WL-OR with wildlife strike risk information provided by WCU and ENH_WL-VS with wildlife strike risk information presented on the radar display. All displayed bar charts represent average values for all controllers, with the standard deviation indicated as whiskers. To evaluate the significance of the results, statistical tests were performed. The safety parameters, which were assessed with ordinal metrics, were tested with the Wilcoxon rank-sum test. The efficiency parameters were tested with t-tests. The results of both tests are summarized in Table 3.

3.1 Safety—workload and situation awareness

Mental workload during the simulation, as measured with the ISA scale was, on average, in a range between relaxed (2) and comfortable (3) (EUROCONTROL) as displayed in

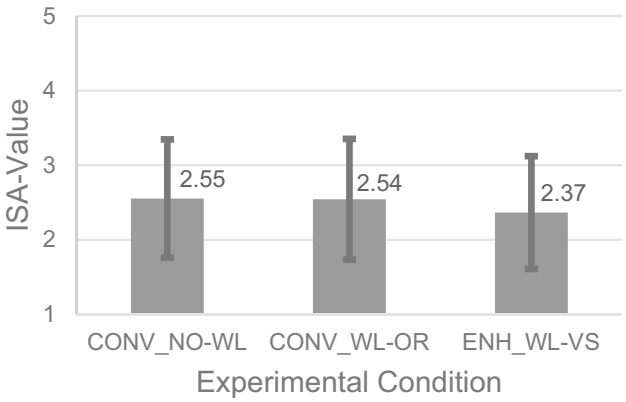

Fig. 4 Self-assessment of mental workload (ISA) per experimental condition

Table 3 Statistical tests for hypothesized variables

Parameter		CONV_NO-WL VS CONV_WL-OR	CONV_WL-OR VS ENH_WL-VS	CONV_NO-WL VS ENH_WL-VS
Safety (Wilcoxon rank-sum test)	Workload	$t=0.30$, $p=0.61$	$t=0.68$, $p=0.25$	$t=0.79$, $p=0.43$
	Situation awareness	$t=-1.39$, $p=0.91$	$t=0.26$, $p=0.60$	$t=-1.10$, $p=0.27$
Efficiency (T-test)	Taxi-in times	$t=1.53$, $p=0.92$	$t=1.01$, $p=0.12$	$t=3.94$, $p<0.05$
	Taxi-out times	$t=-2.80$, $p=0.10$	$t=1.22$, $p=0.87$	$t=-1.74$, $p=0.12$
	Flight duration air taxis	$t=1.91$, $p<0.05$	$t=-0.02$, $p=0.50$	$t=1.35$, $p=0.21$
	Throughput	$t=-0.70$, $p=0.75$	$t=-0.12$, $p=0.45$	$t=-0.80$, $p=0.45$

$n=9$ since one controller did not provide feedback regarding situation awareness

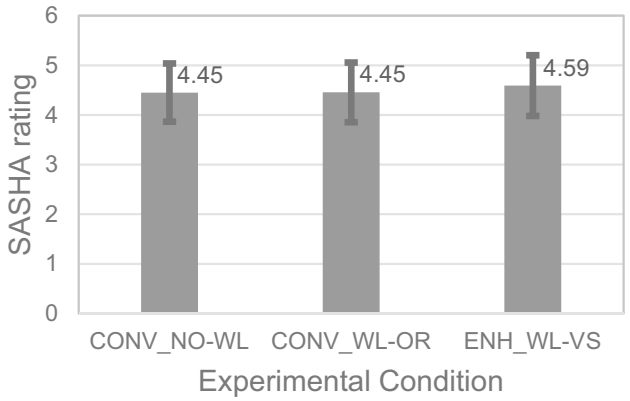

Fig. 5 Self-assessment of situation awareness (SASHA) per experimental condition

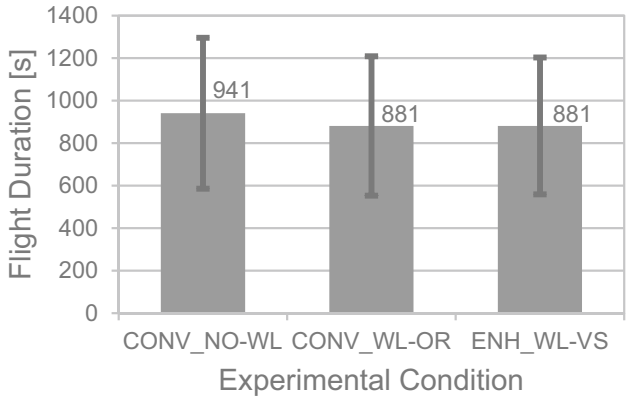

Fig. 7 Average air taxi flight duration per experimental condition

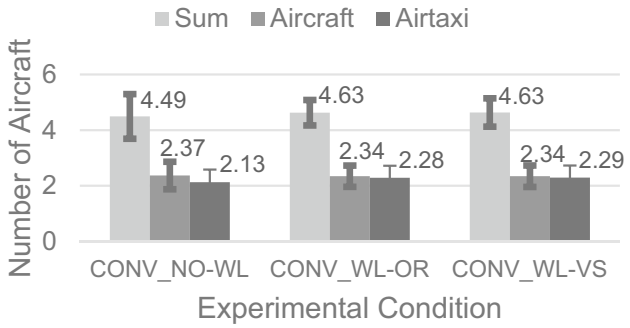

Fig. 6 Average throughputs per experimental condition

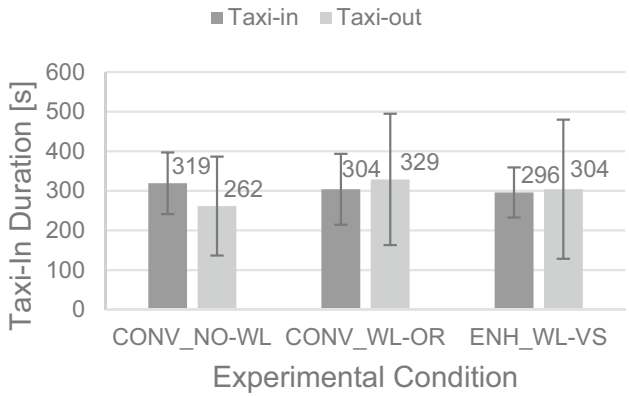

Fig. 8 Average taxi times of conventional aircraft per simulation condition

Fig. 4. The results are similar for conditions CONV_NO-WL and CONV_WL-OR. The introduction of the enhanced display in condition ENH_WL-VS led to an average reduction in workload of 7%. None of the comparisons led to significant t-test results (cf. Table 3).

The average values for situation awareness are provided in Fig. 5. Including standard deviations, all ratings lie within four and five. As for mental workload, conditions CONV_NO-WL and CONV_WL-OR have a similar outcome. In condition ENH_WL-VS, an average increase of situation awareness by 3% is observed. None of the comparisons led to significant t-test results (cf. Table 3).

3.2 Efficiency

Figure 6 shows the average throughput per experimental condition for conventional aircraft and air taxis.

The overall throughput is lowest for condition CONV_NO-WL. In condition CONV_WL-OR, throughput increases by 5% and in condition ENH_WL-VS by 8%. None of the comparisons led to significant t-test results (cf. Table 3).

When assessing flight times of air taxi aircraft, it can be seen in Fig. 7 that their duration is highest in condition CONV_NO-WL and is 8% lower for both, conditions CONV_WL-OR and ENH_WL-VS. The reduction from condition CONV_NO-WL to condition CONV-WL-OR was significant (cf. Table 3).

Average taxi-in and taxi-out times of conventional aircraft are presented in Fig. 8. The average taxi-out time increased by 23% when including wildlife information in condition CONV_WL-OR. With the enhanced radar display in condition ENH_WL-VS, that increase was reduced by 8% to 15%. The average departure delay due to wildlife strike prevention amounted to 67 s. None of the comparisons led to significant t-test results (cf. Table 3).

While taxi-out times increased, taxi-in times decreased. In condition CONV_WL-OR, average taxi-in times reduce by 5% in comparison to condition CONV_NO-WL. In condition ENH_WL_VS, an additional 3% reduction was achieved, leading to an average reduction of 23 s. The t-test confirmed that this reduction led to comparable taxi-in times

Table 4 Average ATCO ratings on acceptability and usability for the enhanced airside situation display

Category	Initial study [14]	Present study
Acceptance—overall (TAS)	72 (SD = 16)	78 (SD = 14)
Acceptance—usefulness (TAS)	86 (SD = 19)	87 (SD = 13)
Acceptance—satisfiability (TAS)	86 (SD = 20)	93 (SD = 7)
Usability (SUS)	81 (SD = 14)	85 (SD = 7)

between conditions CONV_NO-WL and ENH_WL-VS (cf. Table 3).

3.3 Enhanced display acceptability and usability

To evaluate the design of the enhanced radar display, acceptability and usability were rated by the ATCOs with questionnaires covering TAS and SUS. The resulting average scores were compared with the ratings in the initial study, after which the display design was adapted according to ATCO feedback [14]. Table 4 shows the results of both studies.

All aspects of acceptance and usability scored higher in the present study than in the initial one. Moreover, the standard deviation of responses was lower for the present study in all instances.

In the post-run-questionnaire as well as the final debriefing, ATCOs provided feedback on their overall impression of the additional display elements. All of them consider the cone shape to visualize potential future wildlife positions as intuitive. Four ATCOs appreciate the color-coding to differentiate between high and medium severity of potential strikes, for five, it did not provide additional use. One ATCO did not provide feedback. To limit elements shown on the radar display, wildlife labels with additional information were only presented to controllers on demand. This choice was confirmed by the majority of ATCOs—nine prefer to see the label information as well as the previous part of the trajectory on demand, while one would prefer to see it all the time.

Table 5 shows how relevant the ATCOs consider the individual label elements, in percentages. The ATCOs rate height by means as the most important element, with 98% of agreement that it should be provided. One ATCO even suggested to show this information as an integral part of the cone, visible at all times, and to provide an altitude band rather than a discrete altitude where to expect wildlife. In addition, the previous part of the trajectory and bird classification (individual/flock) is considered as highly relevant, with 82% agreement for both. The ATCOs consider risk, velocity and time to intersect as informative, but less relevant. However, these three average ratings all have high standard deviations, indicating high variation in responses. Two ATCOs suggested to show the label upon hovering over the wildlife target rather than by clicking on it to reduce display interaction.

Table 5 ATCO ratings on the relevance of label elements

Parameter	Average	Standard deviation
Previous track	82	17
Bird type	82	17
Time to intersect	69	30
Risk	73	26
Height	98	6
Velocity	69	27

The highlighting of UAM colors in case of potential conflict with wildlife was appreciated in current form by six ATCOs. The other four saw it as less relevant or preferred a reduction to highlight only the predicted intersection point.

3.4 Use of wildlife strike risk information

Finally, individual ATCO feedback on the simulations and the display design was gathered in questionnaires with free-text fields and in a debriefing after the final simulation run. There was a general agreement among ATCOs that wildlife strike risk information provided directly to them is helpful. In contrast to information received from the WCU, they can assess the risk by themselves and can better plan their actions. Eight ATCOs would prefer to provide pilots of conventional aircraft with concrete risk information, delegating the decision to delay a take-off or adjust the climb rate to them. In case of UAM, nine ATCOs would prefer this option over advising pilots on how to react to the threat.

4 Discussion

It was hypothesized that the introduction of wildlife activity in condition CONV_WL-OR would result in slightly increased workload, reduced situation awareness and a wee reduction in efficiency. Supporting controllers with the enhanced display in condition ENH_WL-VS was expected to reverse these effects to values comparable in the baseline without wildlife, CONV_NO-WL. Even though the averages indicate support of the hypotheses (cf. Table 1), they have to be rejected due to non-significant t-test results with two exceptions. Hence, the observed results may indicate tendencies but will need confirmation with a higher number of participating ATCOs.

4.1 Safety—workload and situation awareness

ATCOs evaluated their mental workload between "relaxed" and "comfortable for all conditions. The situation awareness values were reported to be comparable between conditions, with a slight increase in the third condition ENH_WL-VS. This is true for average as well as for standard deviation ratings. The introduction of the enhanced radar display (condition ENH_WL-VS) led to a slight increase of situation awareness and a slight decrease of mental workload. This indicates a successful support of ATCOs in their additional tasks. The potential for workload reduction due to wildlife strike risk information as described in Hale and Stanley [9] was observed as only marginally taking place in condition CONV_WL-OR and slightly clearer in condition ENH_WL-VS. All of the observed changes between conditions are non-significant. Still, they may indicate that the consideration of wildlife strike risk for fixed-wing and UAM traffic may be feasible from an operational point of view for all tested non-local ATCOs and for the simulated airport of Hamburg during peak hour.

4.2 Efficiency

Despite similar mental workload and situation awareness in conditions CONV_NO-WL and CONV_WL-OR, the throughput of aircraft and air taxi movement increased from the former to the latter. This unexpected increase might point towards a training effect over the different simulation runs. As described earlier, between the simulation runs of condition CONV_NO-WL and CONV_WL-OR, the ATCOs performed in two additional runs of the partnering study of this work [15]. These may have contributed to getting better acquainted with the airspace of Hamburg and with the procedures to handle UAM traffic. Supporting this assumption is the steeper increase in throughput observed in condition CONV_WL-OR in comparison to the further gain in condition ENH_WL-VS.

Considering the flight times of air taxis, the value visualization of UAM routes in the CONV_WL-OR and ENH_WL-VS runs seems to have compensated for the additional workload due to wildlife risk information handling since a reduction was observed in both conditions. This is supported by overall mental workload reports which were similar or even lower than in condition CONV_NO-WL. The significant reduction in flight times from condition CONV_NO-WL to condition CONV_WL-OR supports this explanation. Moreover, increased alertness to wildlife strike events by the controllers may have contributed to their efficient handling.

The consideration of wildlife strike risk did lead to increased taxi-out times and thus to take-off delays. However, these are all well below the ending of the slot window which closes ten minutes after the assigned take-off [26]. In addition, despite these delays, the runway throughput was even increased in the conditions considering wildlife strike risk. More efficient provision of clearances due to enhanced situation awareness and reduced mental workload seem to compensate the delays. Thanks to the average reduction in taxi-in times, increased fuel burn due to take-off waiting is limited. The reduction in both types of taxi times from condition CONV_WL-OR to condition ENH_WL-VS is consistent with ATCO reporting of the enhanced radar display enabling them to provide more specific warnings and thus shorter delay times and optimized crossing clearances.

4.3 Enhanced display acceptability and usability

The display design received high average rankings considering acceptance and usability, with low standard deviations, indicating high contentment by the ATCOs. The increased ratings compared to the initial demonstrates the value of the adaptations performed between the studies.

4.4 Use of wildlife strike risk information

The overall feedback of the ATCOs towards integrating wildlife strike risk information into the radar display was favorable. They appreciate the increased situation awareness and ability to provide pilots with dedicated risk information. The selected visualization is perceived as intuitive and supportive. The increase in rated acceptability and usability, alongside reduced standard deviations indicate a successful improvement from the initial design [14]. The main mentioned prerequisites for implementations are sufficient filtering to avoid overload of the display and reliability of information shown. Individual feedback on adaptations of the visualization could in practice be accommodated by adaptability for individual users, which, according to feedback by the ATCOs is common in ATC tools. Operationally, provision of information rather than advisories to pilots is preferred by the majority of ATCOs. Thereby, it should be ensured that mental workload does not focus too strongly on wildlife strike risk. Since controllers reported a reduction in mental workload with increasing use of the enhanced display in contrast to interaction with WCU, this issue would resolve itself by the course of time. Lastly, exclusions of legal consequences for ATCOs in case of strikes still occurring must be guaranteed.

5 Conclusions

The present study evaluated the effects of providing tower ATCOs with wildlife strike risk information when controlling both, conventional fixed-wing aircraft and air

taxis at the airport of EDDH by performing real-time HIL simulations. The setting of the simulations was very specific and the observed results mostly insignificant. Nevertheless, they do indicate some promising tendencies to be confirmed in future studies The conclusions are strengthened by the usage of different metrics, both subjective and objective, providing construct validity of the simulation experiments.

All ATCOs, independent of their professional background and despite not being familiar with the working environment at Hamburg airport, handled all planned traffic in all conditions without substantial delays. This indicates both that the handling additional UAM traffic and the provision of wildlife strike risk information are operationally feasible even at a complex airport with intersecting runways and during peak hour. In the conditions including wildlife strike risk information, even a capacity increase was observed despite this additional element, highlighting the value of training.

A prerequisite for actual integration of UAM traffic and the inclusion of wildlife strike risk are clearly defined procedures for handling these additional airspace users. Here, this study tested a concept which should now, based on the observations and the feedback of the participating ATCOs, be refined to get another step closer to its integration. Moreover, a distinct and intuitive terminology for different risk levels should be developed. While this study focused on the ATC perspective, future research should address the usage of wildlife strike risk information in the cockpit.

With emphasis on wildlife strike risk information, departure delays of conventional fixed-wing aircraft are in highly tolerable limits. The reported increased situation awareness and lowered workload, combined with the high ratings of the enhanced radar display indicate controller acceptance of the concept. Once the logic for a system to provide the required track predictions and risk assessments is available, as well as regulations to exclude ATCO reliability in case of strikes still taking place are defined, an operation in shadow-mode at an airfield already equipped with avian radar should be considered.

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Declarations

Conflict of interests The authors do not have any competing interests to declare.

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