A Human-In-The-Loop Simulation for Urban Air Mobility in the Terminal Area

Anne S. Suzuki
San Jose State University Research Foundation
San Jose, USA
anne.s.suzuki@nasa.gov

Abhinay I. Tiwari
San Jose State University Research Foundation
San Jose, USA
abhinay.i.tiwari@nasa.gov

Quang V. Dao
NASA
Moffet Field, USA
quang.v.dao@nasa.gov

***Abstract*—In this paper researchers propose a human-in-the-loop experiment to study human performance when tasked with tactical deconfliction in terminal area air taxi operations. The air taxi operations being considered herein are an advanced air transportation concept called Urban Air Mobility (UAM). The UAM concept aims to support not only air taxi operations, but also package delivery and emergency response among other use cases. The key innovation over current air transportation lies with the introduction of highly automated aircraft and air traffic management systems. Development of the UAM system will include transitional midterm phases where some operational services will be provided by a mixture of automation and human actors. Midterm operations present a unique challenge, since the scope of responsibility of automated systems is largely undefined, suggesting the need for direct human participation with little to inform how much human intervention is necessary. Here it is assumed that traffic management responsibilities require coordination between human actors and automated systems and focus on arrival flows for midterm operations. In the proposed human-in-the-loop simulation, virtual UAM traffic is strategically deconflicted by a Provider of Services for UAM at departure, then tactically managed by a human at the arrival facility. Generated traffic consists of UAM participants flying in UAM exclusive airspace structures, thus isolated from traditional traffic. The human operator is tasked with managing spacing of arrival traffic and executing speed adjustments as deemed necessary. Researchers propose the investigation of three levels of automation assistance: 1) no assistance; 2) spacing violation detection; 3) spacing violation detection and speed adjustment recommendations. Quantitative measures like throughput and delay are used to assess the human's capacity for accommodating airborne delays. Qualitative evaluations such as surveys and open-ended feedback are used to gain insight into human factors. These factors could introduce additional capacity constraints on traffic, independent of physical or technical constraints. Although findings for this study will not be reported as the study has not yet been executed, the authors conclude with potential outcomes informed by previous simulations in the literature and suggestions for the structure and procedures of midterm human-automation air traffic management.**

Keywords—UAM, strategic deconfliction, air traffic delays, provider of services for UAM, autonomous traffic management, demand capacity management, DCB, PSU

I. Introduction

Urban Air Mobility (UAM) is an advanced air transportation concept that envisions operations over densely populated urban areas, supporting a variety of use cases such as air taxi operations, package delivery, and emergency response. It is expected that key technical innovations – the development of new aircraft, for example, electric vertical takeoff and landing (eVTOL) vehicles, the advancement of onboard equipage, and the introduction of autonomous systems in aircraft and air traffic management services – will be necessary to ensure safe and efficient operations [1], [2]. Furthermore, operators would have the flexibility to fly in both traditional Air Traffic Service (ATS) environments following existing regulations and UAM-specific airspace, or "Cooperative Areas," defined by new regulations [1]. Thus, an emerging theme in realizing UAM is the need to develop new regulations and procedures, in parallel to the technological advances, for UAM integration into the National Airspace System (NAS). The National Aeronautics and Space Administration, the Federal Aviation Administration, and industry have proposed frameworks that share a similar step-by-step integration of UAM into NAS. Traffic density, operational complexity, and the extent to which existing procedures, technologies, and infrastructure are leveraged are commonly used to characterize the progressive stages of UAM and its integration into the NAS [1], [3], [4].

The transitional "midterm" stage from lower density, proof-of-concept UAM operations to higher density, later stages of UAM is generally assumed to consist of medium UAM traffic densities and operational complexity [1]. It is expected that regulatory and infrastructural changes will be necessary to support this midterm stage, and furthermore, that these solutions will need to be scalable to support UAM stages beyond midterm [1], [5]. For example, it is expected that even mid-level traffic densities and tempo will require changes to existing regulations to assist air traffic management services traditionally offered by Air Traffic Control (ATC). Amongst many proposed solutions, this paper focuses on three such enablers. First, UAM vehicles are expected to operate in "UAM Cooperative Areas," airspaces limited to aircraft that meet performance criteria, that separate UAM from traditional air traffic [1]. Second, providers of services for UAM (PSU) are systems expected to distribute air traffic management responsibilities by enabling information sharing amongst UAM participants [1]. Third, new technologies, like autonomous or automation systems, may provide air traffic management services complementary to ATS [1], [2]. However, the scope of responsibility of autonomous or automated systems is largely undefined due to the uncertainty in projections as to what services may be made available midterm. Thus, there is a great interest in exploring human automation interactions that would enable new UAM traffic [6].

In this paper, a human-in-the-loop simulation is proposed to investigate human performance at the arrival terminal area when limited to issuing speed changes. Section II covers previous work. Section III and IV provides experimental assumptions, procedures, and conditions. Metrics and potential outcomes are discussed in sections V and VI, followed by the conclusion in section VII.

II. Previous Work

Current day displays are designed to support a largely human-driven traffic management process. Tools have been developed that have been shown to be generally successful in performing safety-critical tasks, like maintaining separation, traditionally handled by ATC [7]. However, the reallocation of responsibilities introduces the "automation conundrum," in which human situational awareness decreases as automation and autonomous systems capabilities increase in robustness and reliability [8]. This is problematic if the human is expected to act more as a supervisor (i.e., human-over-the-loop), as reduced situational awareness of airspace can compromise the additional level of safety intended to be provided by the human.

Furthermore, a human supervisor must have situational awareness of the automation or autonomous system itself [8]. To supervise effectively, the human will require information regarding the state of automation and autonomous systems [8]. User interfaces must facilitate the proper use of such systems, preventing both overreliance and disuse [8], [9]. Thus, as new automation and autonomous systems are integrated into airspace management, the user interfaces used by air traffic management personnel will also need to change. The displays must address the new requirements of a human supervisor.

The integration of automation and autonomous systems will also require new procedures. Current day procedures rely on human experience and flexibility in adapting to new situations to provide safe and efficient operations. For example, ATC play an essential role in mitigating impacts of system failures and providing graceful degradation when system recovery is impossible [10]. If humans play a critical role in nominal operating procedures or are expected to intervene when automation and autonomous systems fail, human capacity to manually manage aircraft may limit airspace capacity even if automation and autonomous systems enable increased airspace capacity [10].

A human-in-the-loop study can address whether UAM procedures that incorporate increasingly autonomous systems can handle expected UAM traffic loads while also keeping humans appropriately engaged and informed. This paper proposes such a study, focusing on arrival traffic into a terminal facility. Measures like delay are considered to quantify the impact of human intervention. Human factors measurements, workload, situational awareness, and trust in automation, are considered to gain insight into factors that could introduce constraints on traffic levels independent of physical or technical constraints. Because this study is intended to be a preliminary exploration into midterm UAM conditions, many of the conditions are simplified or idealized, and more naturalistic conditions should be considered for future work.

III. Experimental Design

In this proposed study, researchers investigate how airborne uncertainty is tactically managed by a human at the arrival facility. Simulated traffic is deconflicted pre-flight based upon estimated flight times. Statistical error is added to flight times to model real flight. Then, the vertiport manager is responsible for managing the spacing of arrival traffic, aided by a system with varying levels of automation. A summary of the design conditions is given in Table 1.

Table 1 Experimental design

Feature	Recommendation
TLOF	Arrival/Departure only
Strategic Deconfliction	Demand Capacity Balancing + Schedule
Cruise Speed	60 m/s – 90 m/s
Spacing at TLOF	45 sec
Minimum Spacing In-flight	45 sec
Airborne Uncertainty	0 – 5 minutes

A. *Vertiport*

The vertiport configuration is kept simple (Fig. 1), consisting of a single touchdown and liftoff area (TLOF) dedicated to departures or arrivals. The TLOF should define the maximum capacity, a given number of arrivals or departures in a time interval. Ground operations are out of scope. Thus, the vertiport is assumed to have an infinite amount of parking space, so that the vertiport's capacity is never a bottleneck for the network. The design also avoids the placement of the vertiport in a particular geographic area, to minimize factors outside airborne uncertainty that may affect the human performance, as previous work has suggested that geography has impact on workload [11].

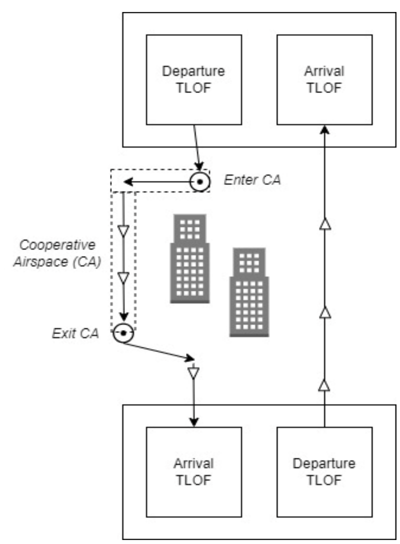

Fig. 1 Vertiport and airspace configuration

B. *Airspace*

All traffic enroute is assumed to operate within airspace exclusive to UAM (i.e. "Cooperative Areas). For the simulation, this entails that all traffic arrives on a single path of arrival to the TLOF. This airspace is understood to have performance requirements, such that all vehicles are expected to have the same range in cruise speed and to be able to execute the same approach. The vertiport manager is tasked with managing traffic that has exited the Cooperative Area and is in the vicinity of the vertiport.

C. *Strategic Traffic Management*

Simulated traffic is assumed to have been strategically deconflicted by some demand capacity balancing system such that the number of operations in a given time does not exceed the TLOF capacity. Multiple demand capacity balancing implementations exist that range in how strictly the capacity is enforced. The strictest implementations apply ground delay to operations to ensure that the estimated future demand never exceeds the resource's capacity [12]. Other implementations apply demand capacity balancing algorithms to a schedule but make no further adjustments [13]. Although looser enforcement of demand capacity balancing has been shown to result in demand capacity violations when flight time uncertainties are introduced, this study presumes that loose enforcement is used [13]. This study presumes that the latter method can balance the safety gained from demand capacity balancing against the decrease in efficiency due to increased ground delay.

Scheduling is also implemented to strategically deconflict operations: within a given interval of time, arrival times at the TLOF are scheduled so that landing events have at least minimum separation. No airborne operations are rescheduled, like scheduling functions found in Time Based Flow Management [14]. Rescheduling is triggered for pre-departure operations, as required when estimated times are outside some time bound greater than the minimum spacing requirement. The relaxed conformance is used because rescheduling was previously shown to drive unscheduled delays [14].

D. *Simulated Traffic*

All vehicles are expected to perform similarly, i.e., having the same minimum, maximum, and cruise speeds, under the assumption that flown routes are limited to certain vehicles meeting certain performance and navigational requirements. It is recommended that the cruise speed be around 60 m/s to 90 m/s, reflecting cruise speeds of developing eVTOLs [15], [16]. The average total flight time from origin to destination is to be in the range of 10 to 20 minutes, consistent with previous work [14]. The simulation of background, large transport commercial or general aviation traffic and any incursions is out of scope for this experiment.

E. *Spacing*

Because all simulated traffic is travelling along the same path, only a minimum longitudinal separation of 45 seconds in-trail for departure and enroute is recommended, consistent with previous simulation studies [14], [17].

F. *Human Actors*

- Vertiport Manager: The vertiport manager is responsible for managing access to vertiport resources, in this case the single purpose TLOF, and airspace immediately surrounding the vertiport. In this design, the vertiport manager is tasked with the management of UAM vehicles only, under the assumption that the airspace is constructed in an area that avoids traditional air traffic flows. Human factors measures in this study will be taken from participants recruited to perform vertiport manager tasks.
- Crew: All vehicles are assumed to be supervised and controllable by the crew. The experiment design is agnostic as to whether the crew is onboard or remote, one-to-one or one-to-many vehicles. In this study, the crew is a confederate, following all procedures and complying with instructions issued by the vertiport manager.

G. *Flight Procedure*

Terminal area procedures have been explored for near term UAM traffic. These studies typically assume that no new ATC infrastructure is necessary. In one such study, ATC participants were tasked with managing both UAM and traditional traffic [11], [18]. Results suggested that simplified voice communication and modified routes were effective in reducing ATC workload [11], [18]. Based on these findings, this study presumes that in midterm operations, UAM vehicles are managed by exception with little to no voice communication.

All vehicles follow the same approach segment to the TLOF. The vertiport manager is tasked with issuance of speed control via voice communications to crew as deemed necessary to maintain minimum separation. No explicit approval (i.e., clearance) is required for the approach and landing, under the assumption that the UAM exclusive airspace and approach segment are defined in a way that UAM vehicles can operate with little intervention from the vertiport manager. Clearance is implicit with operation acceptance, following operational intent submission to the PSU.

Although ATC has various techniques with which to manage traffic flow, like issuing speed adjustments, vectoring, or denying entry into controlled airspace, the vertiport manager in this experiment is limited to issuing speed adjustments. This represents the extreme case of operating under constraints like accounting for limited airspace due to traditional traffic flows, physical obstacles in urban areas, or battery constraints, which may render vectoring or denying entry less practical.

IV. Experimental Manipulations

In this experiment, the vertiport manager is tasked with managing the spacing of arrival traffic. A schedule of flights is strategically deconflicted by a demand capacity balancing algorithm, placing flights into time bins such that the total number of scheduled flights at the arrival facility never exceeds a set number in a given time frame. An example implementation of demand capacity balancing is given in [13]. Flights within each time bin are scheduled such that consecutive flights depart and arrive 45 seconds apart. Airborne uncertainty and levels of automation are manipulated to assess the human and UAM network performance. A sample experiment matrix is given in Table 2 for a 3x3 repeated measures study.

Table 2 Sample experiment matrix

Airborne Error	Levels of Automation		
	Manual	*Conflict Detection*	*Conflict Detection + Speed Recommendation*
0 min			
1 min			
2 min			

A. *Airborne Error*

Airborne uncertainty can result from multiple causes like weather events, differences in vehicle performance, etc., resulting in differences between estimated and actual flight times. In this experiment, statistical error is added to the scheduled flight times to model such in-flight uncertainties that affect real operations. Variations in actual flight times are expected to be smaller than those seen in traditional air transportation due to the shorter flights expected in UAM. It is recommended that the error be modeled in the range of 0 to 5 minutes, comparable to similar, previous simulations [13], [14]. Three levels of airborne error are recommended, including a zero-minute condition for a baseline. Table 2 gives an example using 0, 1, and 2 minutes for airborne error levels.

B. *Levels of Automation*

The vertiport manager is equipped with a user interface that displays information regarding active terminal area traffic and anticipated TLOF use. The schedule for TLOF use is constructed from the operational intents submitted to the PSU and presumed to be shared with relevant vertiport managers.

Three levels of automation are investigated for the traffic management tool: 1) no assistance; 2) spacing violation detection; 3) spacing violation detection and speed adjustment recommendations. In the baseline condition of no assistance, the vertiport manager is given a user interface that displays the arrival traffic on a map and a visual aid that displays both estimate arrival time and scheduled arrival time. A conceptual design of this user interface is given in Fig. 2.

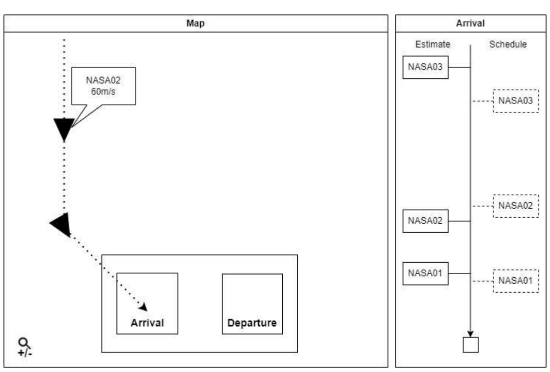

Fig. 2 Sample fleet management user interface.

In the second condition with spacing violation detection, the traffic management tool would at regular intervals check for potential loss of separation between pairs of aircraft and provide warning to the vertiport manager upon detection as shown in Fig 3.

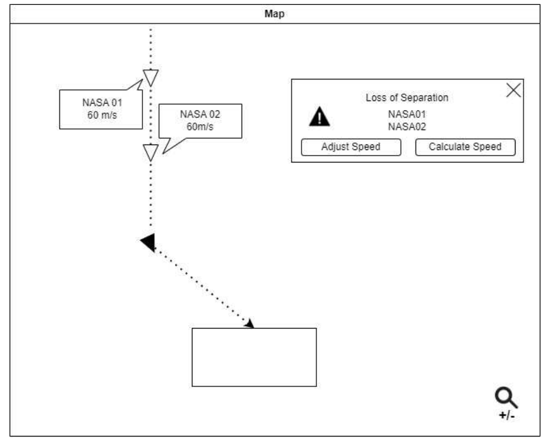

Fig. 3 Notification for LOS event

The user interface should provide an interactive sandbox that allows the vertiport manager to see how changes in speed affect separation. An example is shown in Fig. 4. In the third condition, the traffic management tool also provides the option to generate a recommended speed adjustment. The tool is not assumed to be always accurate. For example, it is not assumed to check whether the generated solution may result in future LOS events with other aircraft. Participants should be encouraged to reject or modify speed recommendations as they deem necessary.

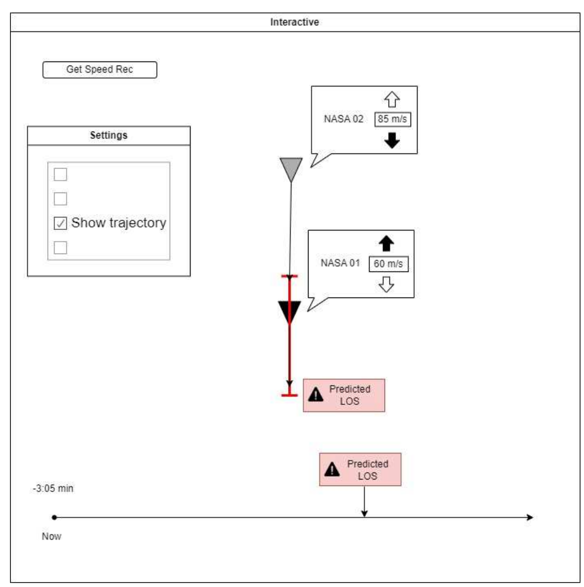

Fig. 4 Interactive tool for adjusting speed.

V. METRICS

The following metrics are suggested by the authors. Throughput and delay measure total network efficiency to see what impact the human operator has on the network. Loss of separation is used to measure safety and its potential tradeoff with efficiency. Human factors measures are also included to provide explanations for the objective measures above.

A. Traffic Throughput

Throughput measures the efficiency of how a resource, like the TLOF, is used. It is defined at the arrival terminal facility as the number of arrivals per given time interval. In this experiment, the capacity of the TLOF equals the theoretical maximum throughput. Instantaneous throughput is measured to compare with the vertiport's capacity. Capacity violation occurs when instantaneous throughput is higher than the set capacity.

B. Traffic Delays

Delay is defined as the difference between the originally requested arrival time and actual arrival time. Ground delay may be imposed by the demand capacity balancing algorithm or pre-departure scheduling. Positive airborne uncertainty may add airborne delay. The vertiport manager may also contribute to delay if operations are instructed to reduce speed for flow management reasons or to achieve minimum separation requirements.

C. Loss of Separation (LOS)

The number of predicted LOS events measures how well the strategic deconfliction method preconditions traffic for the vertiport manager. The actual number of LOS events measures how safely the vertiport manager tactically manages the arrival stream. The duration of LOS events can imply the criticality of the event.

D. Human Factor Measurements

Human factors measurements are collected from participants playing the role of the vertiport manager. Because the experiment design calls for an idealized operational context and is intended as a preliminary study, unobtrusive methodologies are favored over more intrusive and disruptive methods that require psychometric equipment or periodically pause the experiment for data collection. Recommended methods for workload, situational awareness, and trust in automation are given below.

- Workload: It is recommended that workload be assessed via a tool like NASA's Task Load Index [19].
- Situational Awareness: It is recommended that situational awareness be assessed via a tool like the Situational Awareness Rating Technique [20].
- Trust in Automation: It is recommended that trust in automation be assed via a questionnaire, similar to the sample provided by Körber [21]. Trust in automation should be assessed under the manual level of automation condition, even though the user interface only presents information. Ratings obtained under the manual condition should be used as a baseline as they may indicate biases that affect participant interactions with the interface at higher levels of automation.

In addition, participant feedback should be solicited via structured interviews post-trial, post-experiment as they may provide insight into the causes for the self-assessment questionnaire results. Open-ended feedback may also help identify additional capacity constraints on traffic independent of physical or technical constraints and recommendations for the user interface.

VI. EXPECTED RESULTS

The authors offer the following predicted results.

A. Traffic Throughput

Instantaneous traffic throughput should be compared to the arrival terminal's TLOF capacity. Flight time errors are expected to cause capacity violations as shown in Fig 5 as studied in previous work when using loose enforcement of demand capacity balancing [13].

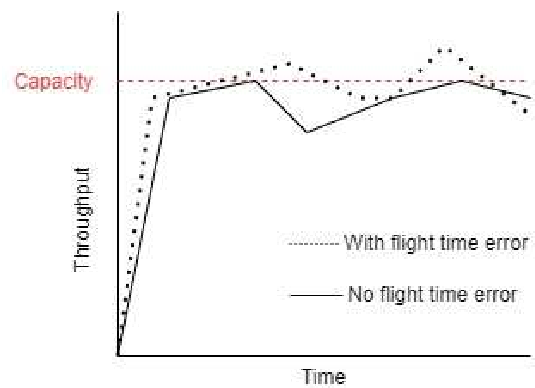

Fig. 5 Capacity violation is expected when flight time error is simulated.

The duration of time in which the network is in a state of capacity violation is expected to correspond to the levels of automation. As traffic management is more manual, more immediate concerns like conflict detection and deconfliction are expected to preoccupy the vertiport manager. At higher levels of automation, the vertiport manager may have the resources to direct traffic to stay within network capacity.

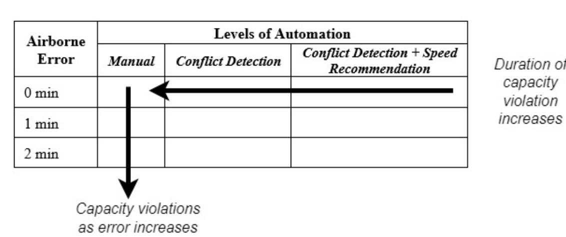

Fig. 6 Expected throughput trends.

B. Traffic Delays

Delay is expected to increase with airborne error, as larger errors can be expected to trigger more rescheduling and add more ground delay as shown in simulation [14]. Delay is also expected to increase when the traffic management is more manual, and the vertiport manager is expected to make time by slowing down aircraft to accomplish a greater number of tasks.

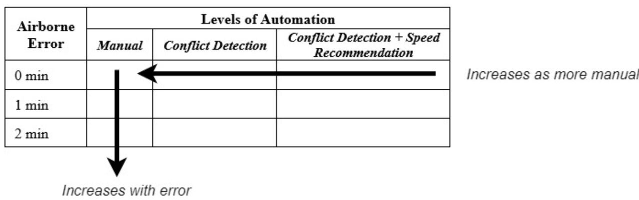

Fig. 7 Expected delay trends.

C. Loss of Separation

The number of LOS events are expected to increase as airborne error, and thus capacity violations, increase. The duration of time for LOS events is expected to increase at lower levels of automation as the vertiport manager is engaged in a greater number of tasks and requires longer times to resolve LOS events.

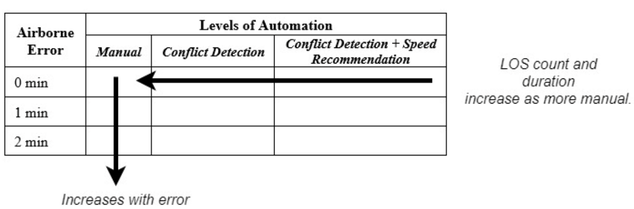

Fig. 8 Expected LOS trends.

D. Workload

The vertiport manager's workload is expected to be greatest when levels of automation are low and is responsible for adjusting speeds manually to ensure separation. Workload is also expected to increase with increased airborne uncertainty, because the number of potential LOS events are expected to increase with uncertainty. The vertiport manager is expected to rely on the speed recommendation calculated by automation more as airborne error increases, to reduce their workload.

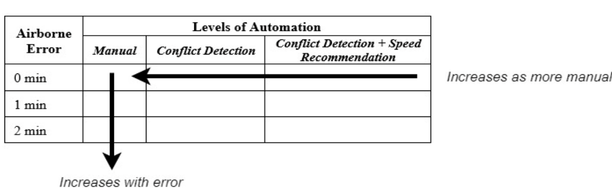

Fig. 9 Expected workload trends.

E. Situational Awareness

Confidence in situational awareness is expected to be lowest when the vertiport manager is required to manage traffic manually and has the additional responsibility of detecting loss of separation. It is expected that the traffic management tool results in confidence overall in self-assessed situational awareness when conflict detection is handled by automation. Confidence in situational awareness is also expected to increase when airborne error is low, and vehicles are arriving closer to scheduled times, allowing the arrival stream to be more predictable to the vertiport manager.

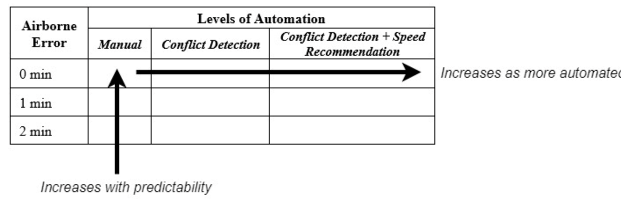

Fig. 10 Expected situational awareness trends.

F. Trust in Automation

Trust in automation is expected to be lower in questions related to competency when the vertiport manager is required to manage traffic manually and has the additional responsibility of detecting loss of separation. It is expected that the traffic management tool results in trust overall in automation when it handles conflict detection.

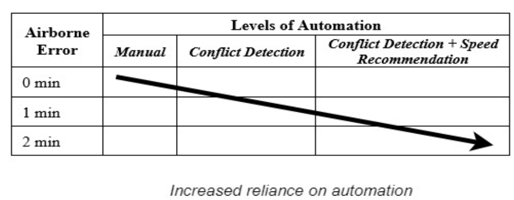

Fig. 11 Expected trust in automation trend.

VII. CONCLUSION

In this paper, the researchers propose a study for evaluating the impact of flight time uncertainties on human-driven traffic management at the arrival terminal facility. The manipulations in this study include Levels of Automation and Flight Time Error; these two variables are fully crossed in the experiment design proposed. Levels of Automation contains three levels that reflect how much assistance is being provided to the human operator; these include, no assistance, conflict detection, and conflict detection with speed recommendations. Flight Time Error also contains three levels, in the range of 0 to 5 minutes. The human role of interest is the vertiport manager, as it is expected to be critical in mitigating delays in the future, such as issuing changes to arrival times to tactically deconflict aircraft and control of the flow of inbound traffic. Thus, participants recruited for this study would be trained to serve as vertiport managers in our scenarios. Metrics for assessing airspace performance are suggested, which include traffic throughput, delay, and loss of separation events. Human factors measurements taken from the vertiport manager position include workload, situation awareness, and trust in automation. Although data has yet to be collected, potential outcomes for this study are discussed.

REFERENCES

[1] Federal Aviation Administration, "Urban Air Mobility (UAM) Concept of Operations V 2.0." Accessed: Feb. 15, 2024. [Online]. Available: https://www.faa.gov/air-taxis/uam_blueprint

[2] D. P. Thipphavong *et al.*, "Urban Air Mobility Airspace Integration Concepts and Considerations," in *2018 Aviation Technology, Integration, and Operations Conference*, in AIAA AVIATION Forum. , American Institute of Aeronautics and Astronautics, 2018. doi: 10.2514/6.2018-3676.

[3] K. H. Goodrich and C. R. Theodore, "Description of the NASA Urban Air Mobility Maturity Level (UML) Scale," presented at the AIAA SciTech Forum, Online, Jan. 2021. Accessed: Feb. 14, 2024. [Online]. Available: https://ntrs.nasa.gov/citations/20205010189

[4] Boeing and Wisk, "Concept of Operations for Uncrewed Urban Air Mobility V 2.0." Accessed: May 21, 2024. [Online]. Available: https://wisk.aero/conops/

[5] E. R. Mueller, P. H. Kopardekar, and K. H. Goodrich, "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," presented at the 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, Colorado, Jun. 2017. Accessed: Mar. 12, 2024. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2017-3086

[6] L. Vempati, V. J. Gawron, and S. R. Winter, "Advanced Air Mobility: Systematic Review of Human Factors' Scientific Publications and Policy," *Journal of Air Transportation*, vol. 32, no. 1, pp. 22–33, 2024, doi: 10.2514/1.D0366.

[7] T. Prevot, J. Homola, L. Martin, J. Mercer, and C. Cabrall, "Toward Automated Air Traffic Control—Investigating a Fundamental Paradigm Shift in Human/Systems Interaction," *Int. J. Hum. Comput. Interaction*, vol. 28, pp. 77–98, Feb. 2012, doi: 10.1080/10447318.2012.634756.

[8] M. R. Endsley, "From Here to Autonomy: Lessons Learned From Human–Automation Research," *Hum Factors*, vol. 59, no. 1, pp. 5–27, Feb. 2017, doi: 10.1177/0018720816681350.

[9] "Humans and Automation: Use, Misuse, Disuse, Abuse - Raja Parasuraman, Victor Riley, 1997." Accessed: Jul. 03, 2024. [Online]. Available: https://journals.sagepub.com/doi/abs/10.1518/001872097778543886

[10] T. Edwards and P. Lee, "Towards Designing Graceful Degradation into Trajectory Based Operations: A Human-Machine System Integration Approach," presented at the AIAA Aviation Technology, Integration, and Operations Conference, Denver, Colorado, Jun. 2017. Accessed: Feb. 27, 2024. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2017-4487

[11] S. Verma, J. Keeler, T. E. Edwards, and V. Dulchinos, "Exploration of Near term Potential Routes and Procedures for Urban Air Mobility," in *AIAA Aviation 2019 Forum*, in AIAA AVIATION Forum. , American Institute of Aeronautics and Astronautics, 2019. doi: 10.2514/6.2019-3624.

[12] S. Chen, P. Wei, A. D. Evans, and M. Egorov, "Estimating Airspace Resource Capacity for Advanced Air Mobility Operations," in *AIAA AVIATION 2022 Forum*, in AIAA AVIATION Forum. , American Institute of Aeronautics and Astronautics, 2022. doi: 10.2514/6.2022-3317.

[13] H. Lee, K. A. Moolchandani, and H. Arneson, "Demand Capacity Balancing at Vertiports for Initial Strategic Conflict Management of Urban Air Mobility Operations," in *2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC)*, Sep. 2022, pp. 1–10. doi: 10.1109/DASC55683.2022.9925753.

[14] A. D. Evans, M. Egorov, and S. Campbell, "Accommodating Operational Uncertainty in Urban Air Mobility Operations with Strategic Deconfliction," in *AIAA AVIATION 2021 FORUM*, American Institute of Aeronautics and Astronautics. doi: 10.2514/6.2021-2333.

[15] "Discover Wisk's Self-Flying eVTOL Air Taxi," Wisk. Accessed: Jun. 10, 2024. [Online]. Available: https://wisk.aero/aircraft/

[16] "Joby Progresses to Next Phase of Aircraft Flight Test Program," Joby Aviation, Inc. Accessed: Jun. 11, 2024. [Online]. Available: https://ir.jobyaviation.com/news-events/press-releases/detail/95/joby-progresses-to-next-phase-of-aircraft-flight-test

[17] S. Verma *et al.*, "Lessons Learned: Using UTM Paradigm for Urban Air Mobility Operations," presented at the 2020 AIAA/IEEE 39th Digital Avionics Systems Conference, San Antonio, TX, USA: IEEE. Accessed: Feb. 14, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/9256650

[18] T. E. Edwards, S. Verma, and J. Keeler, "Exploring human factors issues for urban air mobility operations," in *AIAA Aviation 2019 Forum*, in AIAA AVIATION Forum. , American Institute of Aeronautics and Astronautics, 2019. doi: 10.2514/6.2019-3629.

[19] S. G. Hart and L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," in *Advances in Psychology*, vol. 52, P. A. Hancock and N. Meshkati, Eds., in Human Mental Workload, vol. 52. , North-Holland, 1988, pp. 139–183. doi: 10.1016/S0166-4115(08)62386-9.

[20] R. M. Taylor, "Situational Awareness Rating Technique (Sart): The Development of a Tool for Aircrew Systems Design," 2017, pp. 111–128. doi: 10.4324/9781315087924-8.

[21] M. Körber, "Theoretical Considerations and Development of a Questionnaire to Measure Trust in Automation," in *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander, and Y. Fujita, Eds., in Advances in Intelligent Systems and Computing. Cham: Springer International Publishing, 2019, pp. 13–30. doi: 10.1007/978-3-319-96074-6_2.