# Usability Evaluation of Fleet Management Interface for High Density Vertiplex Environments


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*Abstract*— **To meet the rising demand for an Advanced Air Mobility (AAM) (i.e. urban and rural unmanned aircraft systems) ecosystem, the NASA Aeronautics Research Mission Directorate (ARMD) is hosting a series of simulations and flight tests under the High Density Vertiplex sub-project (HDV) to prototype and study the effectiveness AAM capabilities under various operational contexts. HDV aims to develop an integrated automation architecture to support terminal area flight operations. The HDV simulations and flight tests address safety, integration, and operational challenges, while integrated systems and software demonstrate design readiness, robustness, and interoperability. During the initial HDV simulation in 2021, a prototype traffic management tool developed by NASA called the Fleet Management Interface (FMI) was tested. FMI was designed to introduce an advanced level of human-automation interaction to aid both Ground control systems operators (GCSOs) and fleet managers (FMs) in remotely managing flights under their ownership. In a human-in-the-loop simulation, a usability study was conducted with the FMI to identify optimal approaches for displaying information to human operators using subjective measures of usability, workload, situation awareness, risk, and user experience, along with qualitative feedback. This study consisted of task analysis in which GCSO and FM subjects used an Urban Air Mobility (UAM) environment to develop and execute a plan for two different traffic scenarios of remotely controlled vehicles. In each scenario, a remotely controlled vehicle completed a takeoff, active flight, and landing sequence while simulated traffic flew in the background at a rate of 20 operations per hour. In the first scenario, the controlled vehicle flew a nominal route with takeoff and landing at the same vertiport. In the second scenario, the controlled vehicle started on the nominal route, then diverted to an unplanned location mid-flight. Results showed that self-reported performance, usability, and situation awareness ratings of FMI were moderately high and perceived risk was low. Furthermore, participants described improvements that could be made to create a better user experience. For example, users suggested having the ability to review routes before assigning them, and adding more detail to operation state messages. The results from this study will inform future development of the FMI with the end goal of creating a reference automation tool for airspace management procedures in AAM. The FMI could serve to reduce dependency on traditional air navigation services through increased automation in high density vertiplex environments.**



***Keywords—advanced air mobility, high density vertiplex, urban air mobility, fleet manager***


## I. INTRODUCTION

Opportunities for low-altitude unmanned aircraft system (UAS) operations in many commercial sectors including commercial photography, agriculture, and architectural inspection have created a business boom that allows these operations within the regulatory and operational environment within the National Airspace System (NAS). Operational needs of these small vehicles are propelling public and private stakeholder partnerships with the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) to create a working Concept of Operations (ConOps) for UAS Traffic Management (UTM). The vision is to provide innovative solutions for this air management system while ensuring safety, security, and efficiency of the NAS [1]. Adding low-altitude UAS operations into the NAS presents a multitude of new challenges. The predicted volume of small UAS (sUAS) operations in both controlled and uncontrolled airspace is comparable to that of present-day manned air traffic and makes these challenges even greater. The combined recreation and commercial fleet are projected to reach 2 to 3 million by 2023 up from less than 1.5 million in 2018 [2].

It is the FAA's responsibility to create a framework to allow these vehicles to safely operate in the NAS. This includes creating rules that allow all operators efficient and equitable airspace access. The FAA has worked together with NASA to do that with the development of the UTM framework.

### A. National Campaign

The NASA National Campaign sub-project collaborated with the FAA, UAS industry stakeholders, other government groups and FAA UAS Test sites to develop an operational UTM system to create low-altitude airspace that is safe, efficient, and fair for sUAS operators. By partnering with these test sites, National Campaign was able to conduct UAS tests in geographically diverse locations across the nation. Multiple UAS operations happened at testing sites located in Alaska, Nevada, Texas, North Dakota, Virginia, and New York [3, 4].

### B. High density vertiplex sub-project

A primary focus in developing a workable approach to airspace operations of UAM operations is creating an environment that is safe, scalable, fair, and efficient. A key assumption is that this new system must have a reduced dependency on traditional air navigation systems including air traffic control to increase flexibility and enable the system to grow as needed.

To meet the rising demand for an Advanced Air Mobility (i.e., urban and rural unmanned aircraft systems) ecosystem [5], NASA's Aeronautics Research Mission Directorate (ARMD) is hosting a series of simulations and flight tests under the High Density Vertiplex sub-project (HDV). HDV is focusing on the management of terminal operations and how arrivals and departures of these vehicles can be supported through an infrastructure that can scale to support higher densities expected in the future. The goal is to develop and evaluate an integrated automation architecture and display system to support three roles: the fleet manager (FM), the vertiport manager (VM) and ground control systems operator (GCSO).

One of the tools that was tested during the initial HDV simulation was a prototype traffic management tool called the Fleet Management Interface (FMI) which was designed to aid FMs and GCSOs in remotely managing individual flights under their ownership. Operators must maintain situation awareness, propose routes to the airspace management system, execute plans, manage updates and alerts regarding status of the fleet, and handle emergency or contingency situations that arise. To address these challenges NASA developed the FMI to introduce an advanced level of human-automation interaction to the flight planning and execution process.

The FMI has a graphical user interface (GUI) displayed on a computer monitor which is designed to support situation awareness and optimize operational decision making. Some of the key features include:

- 2D map displays of the airspace, routes, flight plans, and waypoints
- Status of operations such as state changes
- Alert messages regarding critical updates to ongoing operations (e.g., "Replan required")
- Trial planning automation to amend routes while airborne

The FMI tool can be used by human FMs and GCSOs during both simulated and live unmanned aerial flight tests. For this reason, HDV conducted human factors and user experience (UX) research during the initial simulation to identify optimal approaches for displaying information to improve support for operators.

### C. Human factors assessment of Fleet Management Interface

In 2021, HDV completed the Advanced Onboard Automation Simulation (AOA Sim), a human-in-the-loop, task analysis simulation conducted through the combined efforts of NASA Ames Research Center (ARC) and NASA Langley Research Center (LARC) to explore the objectives and research questions are listed below.

*AOA Sim objectives:*

- Collect human factors data through questionnaires
- Understand human performance through user interface interactions, with the purpose of evaluating the design and functionality of the FMI software
- Improve the design of the FMI software through data collected in this usability procedure.

*Research Questions:*

Self-reported and qualitative data was collected to answer the research questions below and to help characterize the problem space. The research questions were:

- What are the FM and GCSO information requirements to accomplish flight replanning?
- Does the FMI provide the user with an adequate user experience (UX)?

The AOA Sim used scripted scenarios including simulated flights and communications between the FMs and GCSOs to assess the FMI in terms of workload, situational awareness, perceived risk, and user experience.

## II. METHOD

### A. Participants

Three FMs from NASA Ames and six GCSOs from NASA Langley participated in this study. Participants were recruited through the available staff at each center. There were no prerequisites for FM participation. GCSO participants were authorized and trained as sUAS flight crew. The characteristics for FM participants areas of expertise were a background of human factors and aeronautics or air traffic control research with an average of 18 years of experience (min=8, max=30). The characteristics for GCSO participants areas of expertise were primarily sUAS piloting or engineering background with an average of nine years of experience (min=1, max=32).

### B. Scenarios

There were two scenarios (Scenario 1, Scenario 2) in which the FM and GCSO were asked to complete manual tasks. Both scenarios consisted of 21 aircraft, 20 were automated by simulation software and 1 was controlled by the human operators. All traffic was scheduled to both take off and land at Vertiport 1. Vehicles took off approximately every 2.8 minutes for a rate of 20 operations per hour.

In Scenario 1: Nominal automated landing at vertiport, (Fig. 1) all flights were assigned a nominal flight plan with automated landing at a scheduled vertiport. The FM assigned a time slot for the controlled vehicle and the GCSO loaded the flight plan, then the system executed the automated takeoff and landing procedure. In Scenario 1, flights completed their planned operations according to what was originally filed.

Fig 1. Diagram of the nominal route in Scenario 1.

Scenario 2: Diverted route and automated landing at unscheduled alternate vertiport, (Fig. 2) began with all flights sharing the same nominal flight plan as in Scenario 1. When the controlled vehicle was approximately halfway through the flight, Vertiport 1 was closed forcing an automatic "replan required" message to display on the FM and GCSO displays. The FM then manually engaged the Trial Planner function on the FMI and selected a viable reroute option which was uploaded to the GCSO workstation. The GCSO then manually downloaded the new flight plan. After the new flight plan was accepted, the system changed the course of the aircraft and executed the automated landing sequence.

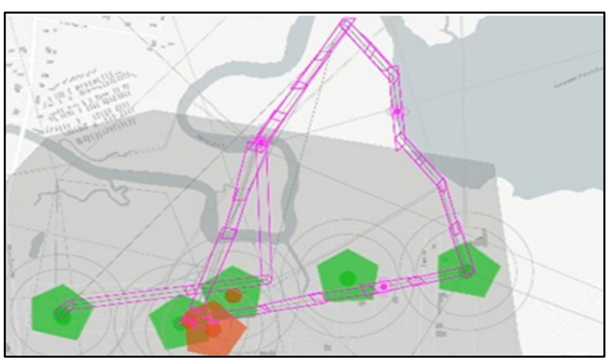

Fig 2. Diagram of the diverted route with automated landing and unscheduled alternate vertiport in Scenario 2.

## C. Tools

*a) FMI:* The Fleet Management Interface is software that is designed to support operations flying below 122m AGL and integrates with external systems to make operational context available to the human operator. These systems include the vehicles, control stations, airspace management functions called NASA Provided Services for UAM (NPSU), as well as supplemental data service providers (SDSP), and simulation platforms that feed traffic to the user interface like Multi Aircraft Control Systems (MACS). In this study, FMI was used as the primary workstation for the FM position, and as a component of the workstation for the GCSO position. The FM workstation consisted of a map with airspace structures, a table with for scheduling operations, and a table for all operations and messages. The GCSO workstation had a map, operation status table and messages. There were other components of the GCSO workstation in addition to the FMI that were evaluated under a separate HDV human factors study [6].

*b) Trial Planner:* The trial planner is a feature of the FMI display that allowed the FM to see rerouting options for a given terminal control area. If a previously accepted operation suddenly became inviable, such as a destination vertiport closure (e.g., Scenario 2) a "required reroute" message was automatically triggered in the FMI, alerting operators that a new operational plan needed to be submitted. The operation that required modification was highlighted on the operations table, signalling the FM to engage the trial planner and propose a new operation. The trial planner generated rerouting options between vertiports by using arrival routes with predefined entry points to which a transitional path and approach segement was computed dynamically from the position of the aircraft. Once proposed by the FM, the new flight plan could be loaded by the the GCSO and the operation would automatically update in the FMI.

## D. Measures

To evaluate human performance on assigned tasks and assess the usability of FMI, self-report surveys were administered to participants and user interactions with the interfaces were recorded. Four subjective rating questionnaires were administered to the participants across twelve runs. Three questionnaires were completed between-runs, and one was completed post-experiment. Following each scenario, all participants completed the NASA Task Load Index (TLX) [7], the Situation Awareness Rating Technique (SART) [8], and Perceived Risk [9] questionnaires. At the conclusion the experiment, all participants completed an FMI Usability questionnaire with custom questions generated by the researchers. Throughout the questionnaires participants were asked to provide written feedback on their experience, ask questions, or give more context to their answers on the questionnaires.

## E. Procedure

For this study, participants were asked to interact with the display as a supplement to their standard piloting or traffic management tasks while researchers observed the participants' interactions with the FMI under simple flight scenarios.

Upon arrival at the laboratories, participants were asked to complete a demographic and background information form. Before the study began, participants were given a one-hour training session to ensure they knew the aims of the scenario tasks, were comfortable, and knew how to use the FMI. During the training session, a researcher guided participants through a series of tasks, asked scripted questions, and prompted them to interact with certain FMI features.

Three FM participants each ran three half hour runs per day over four days, for a total of twelve runs. Six GCSO participants each ran three half hour runs per day over two days, for a total of six runs. Each flight scenario took approximately 20 minutes to complete followed by a 10-minute interval to fill out questionnaires.

Before the start of the scenario, the GCSO performed a preflight vehicle setup checklist with the simulation operations team, while the FM confirmed FMI connectivity with the simulation environment. Once the simulation director announced the start of the simulation, background traffic started flying the automated scenario.

The FMs task was to manually schedule a time slot for the target aircraft. The FM had to review the FMI schedule table and find an acceptable takeoff time at the departure vertiport and assign the correct route. The FM then submitted the operation plan through the FMI. Once received, the GCSO manually loaded the operation into the FMI and activated. Once the operation reached take-off time, automation took over the execution of takeoff, flight, and landing. During the flight, the GCSO monitored vehicle status, health, and progress, while both GCSO and FM monitored the airspace.

If executing Scenario 1, nominal automated landing at scheduled vertiport, both operators allowed the automation to control the descent and landing sequence. If executing Scenario 2, diverted route and automated landing at unscheduled alternate vertiport, both operators were alerted to the vertiport closure status of Vertiport 1 through a warning message. The FM engaged the trial planner tool to generate a list of three alternate routes and was asked to select single, alternate route. The GCSO received the alternate flight plan and downloaded it through the interface to reach the new vertiport.

After the conclusion of each scenario, participants were given the Between-Runs Questionnaire which consisted of the TLX, SART, and Perceived risk scales. After the conclusion of the experiment, participants completed the Post-Experiment Questionnaire which consisted of the FMI Usability questionnaire. Observational notes and conversations between researchers and participants were recorded throughout the experiment.

## III. Results

The purpose of this study was to evaluate the human performance of manual tasks while using the FMI, and to understand the overall usability of the FMI. The following predictions were made about how the participants would respond to the FMI:

- Overall usability of FMI interface will be moderately acceptable.
- There will not be any major differences between FM and GCSO in terms of performance or usability.
- Differences in ratings could arise due to different domain experience of GCSOs (certified pilots) and FMs (NASA researchers).
- Differences in ratings could also arise from different workstation configurations. GCSOs had more than one type of software application to assist with operational planning, while FMs only had the XTM-Client.

Note, any differences between FM and GCSO scores are reported in this document as "noticeable" differences, meaning there was a delta between FM and GCSO average ratings that was greater than or equal to one point on the 7-point scale. It should be noted that this does not indicate "significant" difference, as hypothesis testing was not conducted.

### *A. Between-run summary for Fleet Managers and Ground Control Systems Operators.*

*a) Task Load Index:* The raw average scores for the TLX (FM = 3.3, GCSO = 3.3) indicated low overall task load across both scenarios (Fig. 1) and high self-assessed performance (FM = 2.7, GCSO = 3.1). The lowest scores were physical demand (FM= 2.6, GCSO = 2.4) and mental/physical effort (FM = 2.9, GCSO = 3.4). Highest rating for both operators was mental (FM = 3.8, GCSO = 4.3) and temporal (FM = 4.3, GCSO = 3.7. There were no noticable differences between GCSO and FM on the ratings.

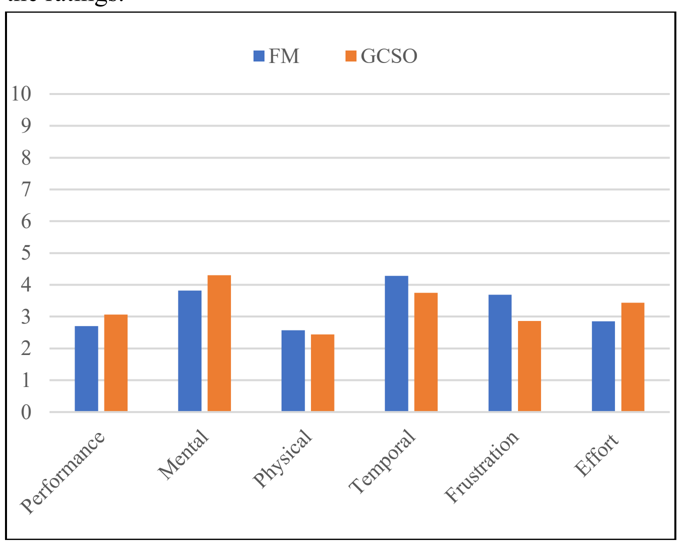

Fig. 3 Raw average scores of TLX for FMs and GCSOs

*b) Situation Awareness Rating Technique*

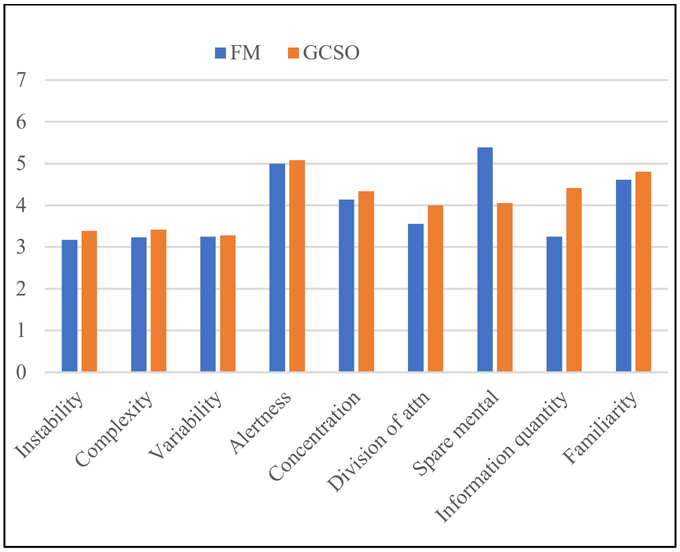


Fig. 4 Average ratings of SART by FMs and GCSOs

The raw average scores of the individual SART dimensions indicated low attentional demand (FM = 3.2, GCSO = 3.4), moderate attentional supply (FM = 34.5, GCSO = 4.4), and moderate understanding (FM = 3.9, GCSO = 4.6) across both scenarios (Fig. 4). Overall, both FM and GCSO responses followed the same trends. FMs reported more spare mental capacity on average (Average = 5.4) than GCSOs (Average = 4.1). GCSOs reported better information quantity (Average = 4.4) than FMs (Average = 3.3), possibly due to differences in workstation configuration.

*c) Perceived Risk:* The raw average scores for perceived risk (FM = 3.3, GCSO = 2.7) indicated low perceived risk across both scenarios. FM and GCSO scores followed similar trends. FM rated riskiness overall trending higher than GCSO, possibly due to domain inexperience.

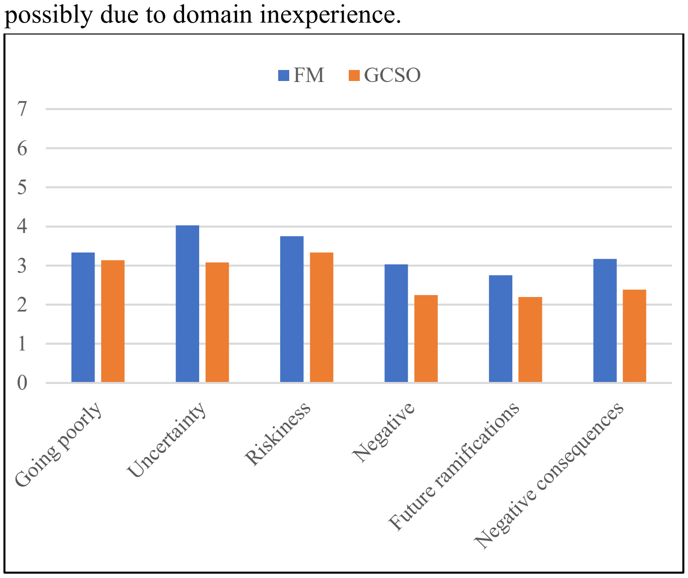


Fig. 5 Average scores of Perceived Risk by FMs and GCSOs

## B. Post-experiment outcome summary for Fleet Manager and Ground Control Systems Operators

*a) FMI User Experience*

The raw average scores for FMI User Experience (FM = 4.1, GCSO = 4.7) indicated moderately positive user experience for the FMI (Fig. 6). GCSOs rated the responsiveness of the FMI as more responsive than FMs (FM = 3.3, GCSO = 4.8). FMs had more exposure to responsiveness issues (bugs) than GCSOs because they had more tasks that required interacting with FMI, and they also interacted exclusively with the FMI. GCSOs used the FMI as more of a monitoring interface and had fewer manual tasks associated with it.

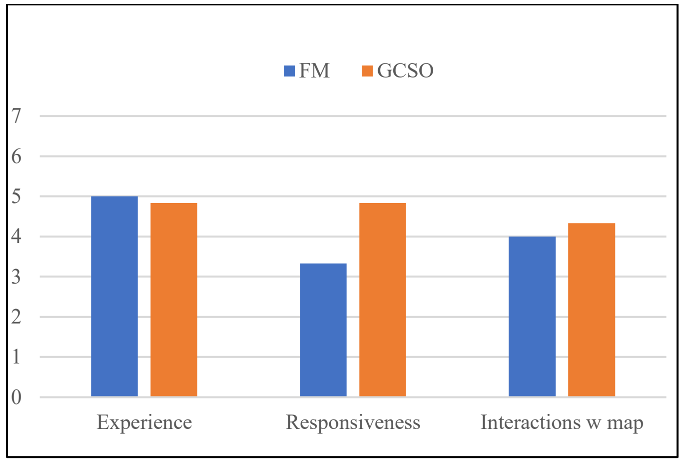


Fig. 6 Average FMI User Experience ratings by FMs and GCSOs

## C. Open Ended Comments

Throughout the data collection process participants were encouraged to provide their feedback and ask questions relating to either the FMI user interface or the study procedures. Commentary from particpants was recorded via open-ended survey, notes, and recordings. The comments were then collected in a comment data base and a frequency diagram (Fig. 7) was generated to select the top comments related to interface design. The most frequently mentioned ares of the interface were the trial planner (20 comments), messages (29 comments), and schedule page (39 comments). The top comments selected from each area we received were:

*a) Trial planner display should show preview of routes:* Nine comments focused on allowing users to review the trial planner routes before selection. The current design lists the alternate routes in a table but does not visually distinguish between each option on the map, as all options are overlayed in a similar manner with neither markers nor interactivity to highlight specific options.

*b) More information on replan and vertiport closure:* Eleven comments showed that more information is needed on vertiport closure and replan notifications to elaborate on why the replan is needed.

| Category | # of comments |
|---|---|
| | |
| User interface interactions | |
| Operations page | 7 |
| Table | 11 |
| Trial planner | 20 |
| Messages | 29 |
| Open row for and individual operation | 9 |
| | |
| Schedule page | 39 |
| Table | 12 |
| Filtering/sorting | 10 |
| | |
| Map | 14 |
| Vehicle data tags | 8 |
| Vertiports | 9 |

Fig. 7 Frequency diagram of top comments related to FMI user interface

*c) Schedule page should sync with operations page and should not be unresponsive:* When the schedule page was being used side-by-side with the map and operations pages, 24 comments showed that the page can be unresponsive for a period of time before it syncs with the other pages.

## IV. Discussion

In general, differences between FMs and GCSOs on the questionnaires were minimal, suggesting that the participants had similar user experiences with the FMI despite having different roles. The FMI is intentionally designed to be flexible and extensible to support a wide range of operational tasks.

Most responses on the questionnaires fell in the range of moderately favorable, with few examples of FMI user interactions generating strong responses, either negative or positive. While self-reported performance was high, situation awareness was moderate. This could mean that participants could perform the tasks well but didn't have enough information to contextualize what was happening in the scenario. Some comments from FMs showed that they had questions about basic elements of the interface related to their tasks, as one FM commented:

*"Notifications for the user should be in plain English, I think they're more developer/programmer oriented now."*

Indicating that some information on the interface was either unnecessary, or difficult to interpret in layman's terms. Another FM commented:

*"It would be nice to have [operation state] messages clarified or defined…I did not have a good feel for what the risk tolerance levels were."*

Researchers noted times when FMs searched for information about an operation and couldn't find it.

So far, open-ended responses remain a rich source of information and practical feedback that we can use to make assumptions about information requirements. More exploration is needed in order to form a reliable definition for the FM role in terms of live sUAS operations.

A limitation of this study was the realism of the flight operations in the scenarios. In both Scenario 1 and Scenario 2, a single, nominal operation would take about 2.8 minutes to complete, which is adequate for demonstrating end to end connectivity between integrated simulation software and automation, but not enough time for performing most manual tasks that human operators are responsible for. For example, in Scenario 2, a mid-flight reroute was required, but FMs did not have enough time to thoroughly review each reroute option that was offered by the trial planner function. To improve FMI usability, several participant comments mentioned the need for a feature that would display more detailed reroute options on the map, presumably to afford greater route review options. For this to be feasible, the nominal flight duration would also have to be extended.

## V. Conclusion

The FMI human factors and usability study revealed low task load, moderate situation awareness, low perceived risk, and moderately high user experience. This study was the first step in assessing FMI human factors for HDV. Subsequent simulations and flight tests are planned for the future which will provide opportunities to iterate the FMI design and test a variety of scenarios.

Future work will consist of exploring the necessary skill level to fulfill the FM operator role. Since the role of FM is still being defined, it is unclear if expert experience is required, or if a novice could fulfill the role. Furthermore, scenarios will be adapted to gradually increase traffic density which will allow HDV to explore the FMI's usability under increasingly complex conditions.

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