Streamlining Tactical Operator Handoffs During Multi-Vehicle Applications ⋆

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Abstract: Increased automation has shifted the operator control paradigm from a single operator controlling a single vehicle, to multiple operators collaborating to control multiple vehicles; this paradigm is known as m:N. Many questions remain unanswered in this new operational paradigm about the division of assets as workload for individual operators varies over time. This paper explores the management of workload by enabling operators to temporarily handoff vehicles among each other. A study was conducted to explore both a manual and assisted method for performing handoffs during manipulated contingency scenarios. The assisted handoff method allowed subjects to easily choose and group nominal and/or contingency vehicles. The number of contingencies was also manipulated to determine the effect workload had on how pilots utilized the ability to handoff vehicles. Results show subjects performed handoffs more often when there were more contingencies and when the assisted handoff tool was available. In addition, the assisted tool made subjects feel more comfortable, enabling them to feel like they could take longer to resolve contingency situations. Lastly, even during contingencies, subjects were able to successfully complete secondary tasks.

Keywords: m:N operations, handoffs, human operator support, shared control, urban air mobility, uncrewed aircraft systems, workload

1. INTRODUCTION

The development of Uncrewed Aircraft Systems (UAS) has drastically reshaped what it means to operate an aircraft. The pilot's removal from the flight deck, the introduction of command-and-control datalinks, and the increased role of automation each fundamentally change the piloting task. While much of the work on UAS to date has focused on a 1:1 control paradigm, in which a single operator controls a single vehicle, a new configuration – referred to as "m:N" – has broadened the approach and evolved the role of a remote operator even further.

Under an m:N architecture, m number of operators cooperatively control N number of vehicles, where N is assumed to be greater than m. Under this control paradigm, operators (i.e., remote pilots) are responsible for a fleet of vehicles but may only have direct control of a subset of them at a given time (Monk et al., 2019). Assets may initially be assigned to certain operators based upon vehicle and/or airspace considerations. However, in certain cases, an operator may need to temporarily transfer (i.e., "handoff") one or more of their aircraft to another operator to ensure their workload remains at a manageable level (Smith et al., 2021). In response to an emergency with one of their vehicles, for example, an operator may decide to handoff the unaffected aircraft in their control so

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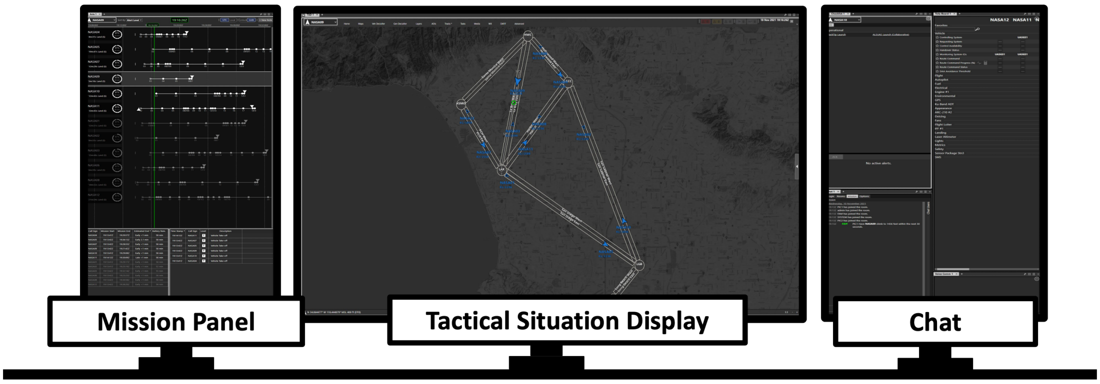

Fig. 1. The displays provided in the simulated Ground Control Station. The Mission Panel is shown on the left, the Tactical Situation Display is illustrated in the center and the chat is provided on the bottom left of the right screen.

that they can devote their attention to the crisis vehicle. The handoff may be pre-planned or ad hoc, depending on the precipitating event.

Earlier research has investigated the ability of remote operators to control multiple small or large UAS when performing traffic avoidance maneuvers (Monk et al., 2019), contingency management (Sadler et al., 2022), and under different levels of automation (Ruff et al., 2002; Fern and Shively, 2009). Fern and Shively (2011), specifically, looked at the effect of display format on remote operators' ability to effectively take control of a UAS in the middle of an ongoing mission. The results of Fern and Shively (2011) demonstrated that display formats that minimize text and emphasize information in a graphical format could reduce response times, reduce workload, and improve situation awareness (SA).

The task simulated in Fern and Shively (2011) was akin to a pre-planned handoff, where an established procedure dictates that one operator handoff a given vehicle to a second operator. By contrast, unplanned handoffs are operator-driven. The operator determines if, and when, to handoff one or more vehicles to a relief operator. The interface elements needed to support an unplanned handoff, and the information requirements for reacquiring control of a previously-transferred vehicle, was the focus of the present investigation.

The aim of the work presented in this paper is to evaluate handoff procedures and assess which unplanned situations lead operators to handoff vehicles in the context of Urban Air Mobility (UAM). A key UAM use case is the utilization of medium-sized UAS to transport passengers and/or cargo within major metropolitan areas and their surrounding suburban regions. The far-term UAM concept of operations assume a high level of automation and high operational tempos, making the m:N control paradigm an appropriate fit (Federal Aviation Administration, 2020). A study was conducted to compare manual and assisted automation handoff methods and their usage during unplanned, on-board vehicle contingency situations.

2. GROUND CONTROL STATION

The Ground Control Station (GCS) used for the study detailed above is built on top of the United States Air Force Research Laboratory's Vigilant Spirit Control Station (VSCS) software. VSCS provides a graphical user interface (GUI) for operator control of multiple vehicles and includes functions such as alarms and warning systems, checklists, emergency procedures, an event timeline, and a chat tool. Leveraging the baseline functionality from VSCS, the GCS (Fig. 1) provides a Mission Panel (left), a Tactical Situation Display (TSD, center) and chat window (bottom left of right screen).

The main display used by the operator is the Tactical Situation Display (TSD) shown on the middle screen. The TSD provides airspace and vehicle information on top of the moving map. Operators can use the mouse the scroll in and out and pan to move the map around as needed. Vehicles are shown on the TSD as blue chevrons with data tags that include their callsign, indicated airspeed in knots, altitude (feet/mean sea level) and an arrow indicating if the vehicle is climbing or descending (not shown if the vehicle is maintaining constant altitude). Vehicles in the control of the operator – controlled – are shown as filled chevrons, while those under the control of another operator – monitored – are shown as empty chevrons. By default, each vehicle flies in navigation mode, waypoint-to-waypoint, as part of a predefined flight path. Operators can select a vehicle or group of vehicles by Ctrl+click (left mouse button) or by clicking and dragging the mouse to create a rectangle-shaped area of selection. Selected vehicles are shown with circles around their chevron icons.

The Mission Panel on the left screen consists of the timeline view for all vehicles in the fleet (top), i.e., both controlled and monitored, and a mission status & log (bottom). For the entire Mission Panel, controlled vehicles are shown in white, while monitored vehicles are shown in gray. Events (e.g., next waypoints) for each vehicle are shown as dots in the timeline. A green vertical line indicates the current time. Battery life is indicated by a circle icon showing the percentage and time left until empty. When vehicles are selected on the TSD they are highlighted on the timeline. As on the TSD, an operator can Ctrl+click to select multiple vehicles in the timeline display and the corresponding vehicles will be highlighted in the TSD.

2.1 Contingencies

Over the course of a mission, two types of contingencies occurred on-board vehicles: medical or mechanical. In ad-

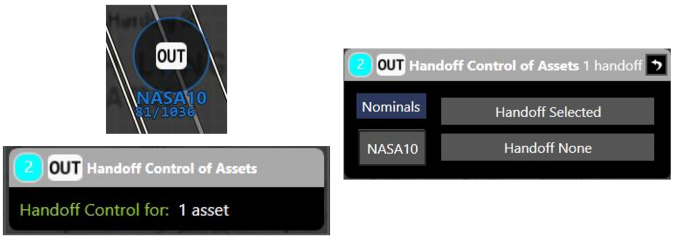

Fig. 2. For assisted condition: “OUT” icon indicating an outgoing handoff request for NASA10 (top left), initial outgoing handoff Toast message (bottom left), and expanded Toast Message (right).

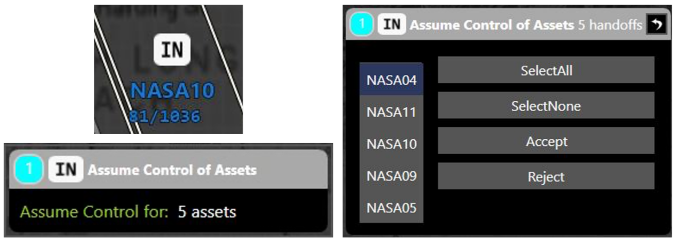

Fig. 3. “IN” icon indicating an incoming handoff request for NASA10 (top left), unexpanded incoming handoff request Toast Message (bottom left), and the expanded incoming handoff Toast Message (right).

dition to the the baseline functionality from VSCS, the GCS provides two visual feedback cues when a contingency is identified on board a particular vehicle under the operator’s control. The first visual feedback is provided when the contingency vehicle chevron and data block change from blue to red. The second visual feedback is a chat message from the system indicating that an emergency has been declared on-board. Along with the two visual cues, an auditory warning is sounded. All visual and auditory cues occur simultaneously. As a status tracking mechanism, an emergency situation prompt appears on the GCS at the same time the visual and auditory cues occur. The prompt asks if the emergency has been resolved, and operators are expected to click the “yes” button after the contingency has been resolved. In doing so, the vehicle’s status goes back to nominal and the chevron and data block will return to the nominal blue color.

To resolve a contingency, the operator is expected to coordinate with the Fleet Area Manager (FAM) to locate a viable landing locations for the contingency vehicle. The GCS provides two additional map overlays that show all viable landing locations (referred to as “vertistops”): a Medical Facilities Layer and an Emergency Landing Sites Layer. The Medical Facilities Layer shows nearby Trauma 1 and Trauma 2 hospitals. Trauma 1 facilities provide a greater array of services but may take longer to reach. The Emergency Landing Sites Layer provides general viable landing locations and indicates whether the destination is an open field or a vertistop. Open fields are simply general open areas large enough to land in without any established infrastructure whereas a vertistop has established infrastructure. Both layers can be turned on and off at the operator’s discretion.

2.2 Handoffs

During contingencies, the workload of operators may be high enough that they may want to temporarily handoff control of one or several of their vehicles to another operator. For the study presented below, there are two methods for handoffs: manual or assisted. For situations where the operator must perform the handoff manually, the operator must first select all the vehicles they would like to handoff. Once selected, they right click anywhere on the TSD display and choose “Handoff Control” from the dropdown menu. This immediately shows an “OUT” icon that flashes over all vehicles chosen for handoff (Fig. 2 (top left)).

At the same time, the receiver of the handoff request sees an “IN” icon flashing over the chevron of all vehicles needing temporary control (Fig. 3 (top left)). In addition, a pop-up banner called a Toast Message appears with an “IN” indicating the number of vehicles whose transfer of control is being requested (Fig. 3 (bottom left)). Upon clicking to expand the Toast Message, the operator receiving the request may manually select the vehicles they would like to “Accept” or “Reject” control over, or use the shortcut buttons available (Fig. 3 (right)). Once the vehicle(s) is/are accepted by the receiving operator, the chevron changes from filled to empty on the initiating operator’s screen, indicating that the vehicle(s) are no longer under their control. Conversely, the chevrons change from empty to filled on the receiving operator’s display.

When the assisted tool is available, an “OUT” Toast Message – similar to the one seen when receiving a request – appears 3 seconds after a vehicle emergency is identified (Fig. 2 (bottom left)). Upon expanding the Toast Message, initiating operators can choose to hand off all nominal vehicles (listed collectively as “nominals” for ease), contingency vehicles, a combination of nominal and contingency vehicles as long as at least one vehicle remains in their control, or choose to handoff no vehicles (Fig. 2 (right)). By providing an easy-to-access list and pre-grouping the nominal vehicles together, the assisted tool enables the subject to initiate handoffs without needing to manually select the vehicles from the TSD. However, operators can still choose to initiate manual handoffs if they desire to do so.

3. EXPERIMENTAL DESIGN

Sixteen Part 107 Certified pilots participated in the study (14 male and 2 female). The average age of subjects was ∼34 years old. Fourteen subjects had crewed flight experience with an average of 1720.5 flight hours, and 12 subjects had uncrewed flight experience with an average of 770.44 flight hours. Eleven subjects were IFR rated and all subjects were Part 107 rated.

The experiment employed a 2 × 2 within-subjects design where each subject participated in 1 trial for each of the 4 experiment configurations. For each trial, subjects took on the role of a Tactical Operator (TO) and were asked to work with another TO (who was played by a researcher) to manage the operations of 12 highly automated electric vertical takeoff and landing passenger aircraft. Each TO was initially responsible for 6 vehicles. The airspace utilized dedicated UAM corridors to connect 6 different

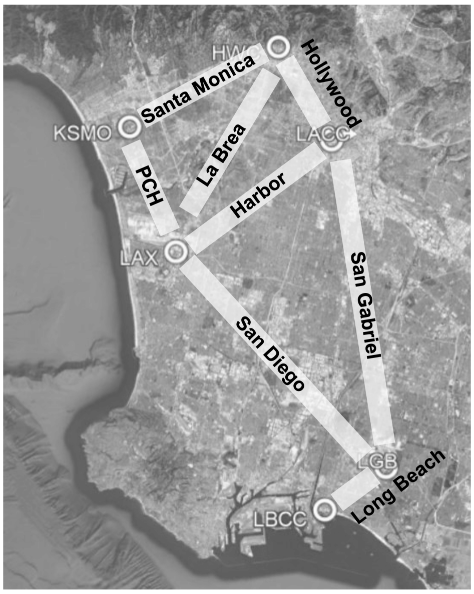

Fig. 4. Simulated airspace and corridors used for the study. Circles indicate vertiports. Corridors are depicted as white rectangles.

vertiports (i.e., UAM landing and takeoff facilities) in the Los Angeles area (Fig. 4). As part of each trial scenario, vehicle(s) experienced medical and/or mechanical issues that required the vehicle(s) to be directed to appropriate sites for immediate landing. If too much workload was felt by the subject then they were able to temporarily hand off some portion of their managed assets to the other TO. The study manipulated (1) workload through the number of vehicles that experienced contingencies (low=1 vehicle or high=2 vehicles) and (2) the handoff automation level (manual vs assisted). The trials were blocked by automation level. The order of presentation of the automation level, and the trials within in automation level block, were counterbalanced across the subjects.

Single contingency scenarios always produced a medical emergency. Double contingency scenarios always produced 1 medical and 1 mechanical emergency, with the second contingency appearing 3 seconds after the first. One of the 2 contingency scenarios had a medical contingency appear first, while the other had a mechanical contingency first. When a contingency appeared, text-based chat messages provided subjects with information on which vehicles had emergencies and what type of contingency they were experiencing. These messages were provided automatically by the system. The FAM coordinated separately with an Emergency Service Provider (ESP) to provide the TO with 3 landing site options. The subject was required to choose from the options based on the expected time to reach them. Once chosen, the subject informed the FAM of the landing site and a reroute for the affected vehicle was sent to the subject through the GCS. The subject was then able to accept the new route. Once a vehicle rerouted, the contingency was deemed resolved and the subject could indicate so by clicking the "Yes" on the emergency situation resolution prompt, which appeared during the onset of the contingency. All system notifications and communication between the subject and the FAM were conducted through the text-based chat. This study used simplified communications (comms) to ensure that handoff workload results were not conflated with complexities due to comms. A future study will examine comms with ATC.

For the manual automation condition, handoffs required manual selection of vehicles and a manual initiation of the handoff request. Manual handoffs could occur at any point within the trial. During each of the 4 trials, subjects were also asked to respond to 4 different calls (via the chat) from the FAM which required altitude or speed adjustments to a particular vehicle. Each trial contained 1 ascend command, 1 descend command, 1 speed up command, and 1 slow down command. Two FAM calls occurred before any contingencies, 1 FAM call happened during the contingencies, and 1 FAM call happened after all contingencies were resolved. The order of the types of calls given was counterbalanced across the trial configurations.

After completing an informed consent form and background questionnaire, subjects were given general training covering the goals of the study, a description of the airspace that would be used in the trials, and an overview of the GCS. The basic controls available to the subject were then explained and they were allowed to practice the basic controls in a test scenario on the actual GCS to become familiar. The handoff procedure was then explained, which was then followed by an additional practice in an example scenario. Due to the blocking of trials by automation level, only the handoff procedure for the first block was explained initially. Next, an overview of the 2 types of contingencies expected and the procedure for resolving them was given. Subjects were provided with time to practice medical and mechanical contingency resolutions within both single and double contingency scenarios. Initial training ended with an overview and practice secondary tasks (FAM calls). After the trials for the first block were completed, the handoff procedure for the second block was explained followed by additional hands-on training and the completion of the remaining trials.

After each trial, subjects completed a post-trial questionnaire that included the NASA TLX (Hart and Staveland, 1988; Byers et al., 1989) and questions about their workload at various portions of the scenario, if they had handed off any vehicles and why. They were also asked about the effectiveness of the interface, the difficulty of the interactions with the FAM, the difficulty of managing their assigned assets, and the difficulty of the contingency resolution. After all trials were completed, a post-simulation questionnaire was given and included general questions about training, the GCS interface, how useful the FAM was in resolving the contingencies, the resolution procedure, the simulation environment, and the usefulness of the assisted prompt. The day ended with a verbal discussion between the subject and the researcher during which the subject was able to provide insight into the decision making process and provide general comments. Topics included the trials in general, procedures used throughout the day, the GCS, automation tools for aiding in handoffs, and interactions with the FAM and other TO.

4. RESULTS

Separate 2 (manual vs. assisted) x 2 (low vs. high workload) repeated measures ANOVAs were conducted on the

	1 Contingency	2 Contingencies	Manual	Assisted
Workload Before	1.41	1.47	1.38	1.50
Workload During	3.13	3.69	3.63	3.19
Workload After	1.47	1.69	1.59	1.56
Satisfied with handoff decision	4.59	4.06	4.00	4.66
Interfaces allowed me to perform handoffs in a timely manner	4.16	4.06	3.91	4.31
Interactions with FAM were manageable	4.09	3.94	3.97	4.06
Interactions with ESP were manageable	4.23	4.16	4.09	4.28
Number of controlled and monitored aircraft was manageable	4.56	4.47	4.47	4.56
Emergencies were manageable	4.50	4.31	4.38	4.44

Table 1. Percentage of time handoffs occurred and post-trial subjective ratings on overall workload, interactions and difficulty of tasks.

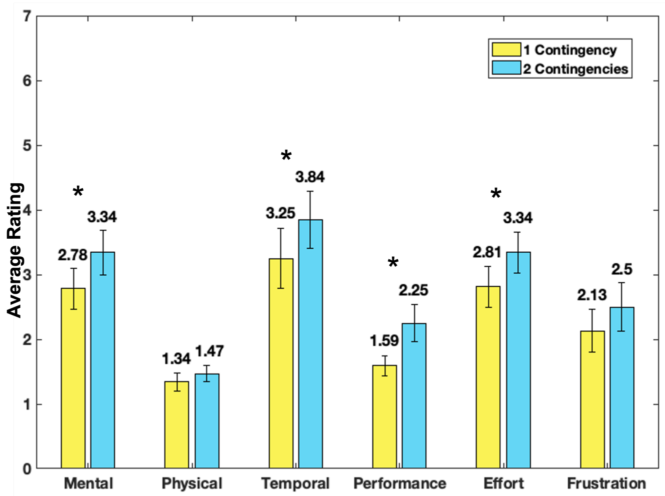

Fig. 5. Average NASA TLX ratings by number of contingencies seen.

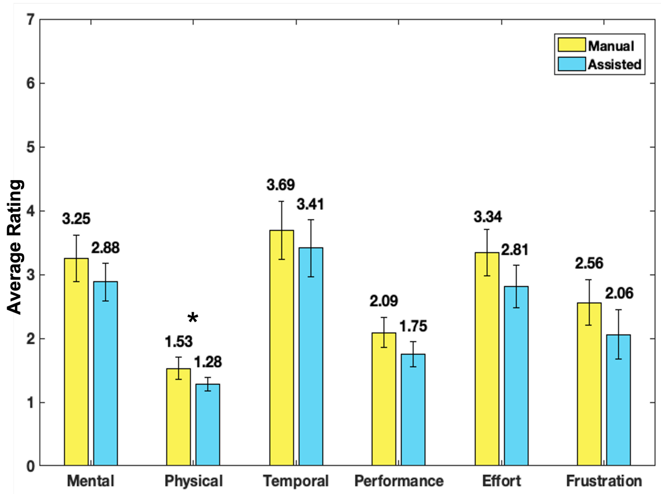

Fig. 6. Average NASA TLX ratings by automation level.

data using IBM SPSS version 28. The analysis examined whether the experimental manipulations affected measurements such as workload, subjective questionnaire responses, number of handoffs, and resolution time. Sphericity was assumed for all analyses. Results are reported using a significance level of $p < 0.05$. Error bars are shown for the standard error in all bar graphs. Statistically significant results are marked with a * symbol.

4.1 Subjective Measures

Figures 5 and 6 show average post-trial NASA TLX workload ratings by number of contingencies and automation level. The differences between ratings for 1 contingency vs. 2 contingencies in a given trial is statistically significant for all subscales except for Physical and Frustration (Fig. 5). Workload rating differences between the manual and assisted condition were statistically significant for the Physical subscale (Fig. 6). Results show that workload ratings were higher during trials that included 2 contingencies as opposed to those with only 1 and in manual trials as opposed to the assisted trials.

Subjects performed handoffs more often in trials where 2 contingencies were present than in ones where there was only 1 (84% vs. 44%) and more often in assisted trials than manual ones (73% vs. 56%). Average post-trial subjective question ratings are also shown in Table 1. All questions were asked using a 5 level likert scale where the dark gray highlighted questions ranged from 1 being extremly low to 5 being extremely high and the light gray highlighted questions ranged from 1 being strongly disagree to 5 being strongly agree. Workload during contingencies was the highest, followed by workload after the contingencies, which was slightly higher than workload before the contingencies. In general, subjects were satisfied with their decisions, the interactions they had with the interfaces and other roles, and their ability to control and manage vehicles.

4.2 Contingency Responses

Overall, if subjects chose to handoff vehicles, they handed off about 2 vehicles no matter how many contingencies there were. If they chose to handoff vehicles, they handed off about 1 vehicle during manual trials and 3 vehicles during assisted trials. The difference was statistically significant. In addition, subjects chose to handoff no vehicles 39% of the time on average. They also handed of nominal vehicles 39% of the time. Subjects handed off only contingency vehicles 16% of the time and a mixture of nominal and contingency vehicles 6% of the time. Lastly, the time to resolve a contingency and choose a vertistop was longer for assisted automation conditions (Fig. 7). The difference in time to resolve a contingency seen between the different levels of automation was statistically significant.

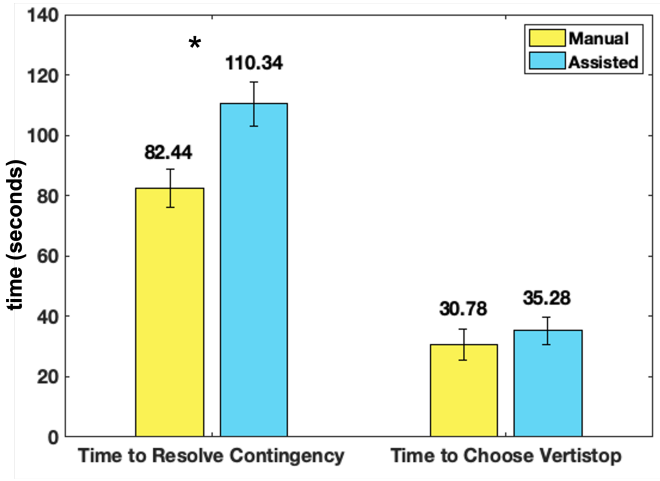

Fig. 7. Average time to resolve contingencies and choose vertistops based on the trial automation level.

4.3 FAM Call Responses

On average, subjects handed off a vehicle if it had a FAM call request associated with it 11.7% of the time. If the vehicle with the FAM call request was not handed off, subjects correctly responded to 94.6% of FAM calls. They sent a follow-up message to the FAM notifying them that the request was completed 95.1% of the time.

5. DISCUSSION

Overall, subjects felt higher workload in the trials with 2 contingencies, which lead to more handoffs than in trials with only 1 contingency. Although the subjects felt higher workload in the manual trials, they chose to handoff vehicles less than when the assisted tool was available. Even though workload was lower in assisted automation trials, subjects took longer to choose reroutes and resolve contingencies, implying that they seemed to feel more comfortable and were not as pressed for time to make decisions. This is also indicated in the subjective ratings showing that subjects felt that interfaces in the assisted trials allowed them to perform handoffs in a more timely manner than in manual trials.

On average, subjects were happy with their decision to handoff or not handoff vehicles. They felt that the interfaces provided enabled them to perform handoffs in a timely manner when they had wanted to perform a handoff. For all trials, workload did not return to the level it was prior to the contingency (or set of contingencies) although it was lower than the workload seen during contingencies. Across the board, subjects felt that the number of vehicles controlled, interactions with others and emergency situations were managable.

Even though some secondary FAM call tasks occurred at the same time as contingencies, subjects rarely chose to handoff the vehicle that had a FAM call associated with it. In addition, they were very successful at completing these tasks. Lastly, subjects very infrequently forgot to notify the FAM when they had completed a request.

6. CONCLUSION

This paper presented methods for Tactical Operators to handoff vehicles to other available Tactical Operators during m:N operations. Handoffs enabled subjects to manage their workload during contingency scenarios. Results show that subjects chose to handoff vehicles more often in scenarios with more contingencies and when assisted handoffs were provided. The assisted handoff tool enabled subjects to feel more comfortable and take their time when mitigating contingencies. Subjects were happy with their decisions and felt that all tasks were manageable. Future work will focus on exploring the impact of different communication modalities with ATC during m:N operations.

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