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TCL4 UTM (UAS Traffic Management) Nevada 2019 Flight Tests, Airspace Operations Laboratory (AOL) Report

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March 2020

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Acronyms and Definitions

4D....................................four dimensional
AOL ....Airspace Operations Lab (Human Systems Integration Division, NASA Ames Research Center)
App...................................(software) application
ARC ....Ames Research Center (NASA)
BVLOS ....beyond visual line of sight
C2 ....command and control
CH ....characteristic
CNS..................................Communication, Navigation, and Surveillance
GPS ....global positioning system
DMP.................................Data Management Plan
FIMS ....Flight Information Management System
GCS..................................Gound Control Station
GCSO...............................Ground Control Station operator
GUFI ....globally unique flight identifier
HSI ....human-system interacrion
ID ....identification
MOE.................................measure of effectiveness
MOP.................................measure of performance
NASA...............................National Aviation and Space Administration
NIAS ....Nevada Institute for Autonomous Systems
PIC ....pilot-in-command
RC ....radio controlled
RID..................................remote identification
RTB..................................return to base
RTL..................................return to launch
SA ....situation awareness
SDSP................................Supplemental Data Service Provider
SOW.................................statement of work
sUAS................................small Unmanned Aerial System
TCL..................................Technical Capability Level
TE....................................test event
UAS ....Unmanned Aircraft System
UAV.................................unmanned aerial vehicle
USS ....UAS Service Supplier
USS Op ....USS System Operator
UTM................................UAS Traffic Management
UVR.................................UAV volume restriction
V2V.................................vehicle-to-vehicle
VO...................................visual observer

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Executive Summary

The Unmanned Aircraft Systems (UAS) Traffic Management (UTM) research project has been developing and testing concept ideas for enabling small UAS (sUAS) operations in low-altitude airspace (ground to 400 feet). To do this, NASA has organized a series of flight test demonstrations. Technical Capability Level-4 (TCL4) flight tests were conducted at a Nevada, USA test site, during June 2019 and a Texas test site during August. The Nevada testing resulted in over 300 data-collection flights using eight live rotorcraft, 15 simulated vehicles, involving six flight crews, and five UAS Service Suppliers (USS). The TCL4 approach was designed to demonstrate five scenarios that set up five diverse sets of UAS events and activities. The Nevada test site focused on three of these scenarios: an incoming weather front, a concert event with an incident requiring an emergency response, and a scenario where multiple sUAS vehicles experienced Communication, Navigation, and Surveillance (CNS) issues. Each of the three scenarios run at the Nevada test site consisted of three phases. Each phase was executed three times, creating a total of nine missions per UAS scenario. This document presents data collected from participants during the TCL4-Nevada June flight test that provides information about how much and how well operators were able to make use of UTM functions and information, with the goal of exploring minimum information requirements and/or best practices in TCL4 operations. The driving enquiry was: how do UTM tools and features support (human) operators leading to safe and effective conduct of large-scale, beyond visual line of sight (BVLOS) sUAS operations in "urban canyon" environments? As with the data collected during previous similar tests (e.g., TCL3, Martin, et al., 2019), the quality of the UTM information exchanged, and the meaningfulness, and therefore usefulness, of this information, were all focal points of the questions asked and the data collected. The results aligned with five human-system attributes to indicate that UTM provided information that contributed to users' ability to operate safely and effectively within UTM operations, but that information was not always complete and was sometimes unclear to the operators.

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1. Background

As part of NASA's Unmanned Aircraft Systems (UAS) Traffic Management (UTM) research effort (Kopardekar, et al., 2016), the Technical Capability Level-4 (TCL4) flight tests were intended to demonstrate small UAS (sUAS) operations in the most complex nominal environment possible and to showcase more complex USS functionality than the previous TCL tests. Two test sites were chosen to work on demonstrations: Lonestar, a Texas A&M University organization based in Corpus Christi, Texas, and the Nevada Institute for Autonomous Systems (NIAS), based in Las Vegas, Nevada, who, for the TCL4 demonstration, operated out of Reno, Nevada. This paper examines the NIAS, Reno, Nevada TCL4 flight demonstration only, further information on the Corpus Christi flight test can be found in Martin, et al. (2020).

The UTM concept combines airspace design, flight rules, operational procedures, ground-based systems, and vehicle capabilities to enable safe and efficient use of class G airspace by sUAS. When extending these operations into airspace over highly-populated and developed areas, the hazards to, and risk level of the operations increase. The high density and fast pace of this arena (see FAA, 2018 or Kopardekar, et al., 2016 for descriptions of the UTM concept), impose more demands on the user to fly safely and efficiently and highlights the need for precise maneuvering to avoid frequent obstacles. To support operators, UTM information, primarily gained through USSs, but also through SDSPs (Supplemental Data Service Providers) and potentially other portals (e.g., remote identification [ID] situation awareness tools), needs to be easily usable in a human factors sense—that is, it must be clear, concise, consistent, understandable, and straightforward (Krug, 2014). If a system is providing users with adequate information, users should report being comfortable with their awareness and with taking actions within the system. Approaching the TCL4 demonstration from the perspective of the user, with the goal of instructing what the minimum information requirements and best practices might be, the driving enquiry was: *How do UTM tools and features support (human) operators leading to safe and effective conduct of large-scale BVLOS (beyond visual line of sight) sUAS operations in "urban canyon" environments?* To address this question, participants were asked for feedback about the properties of UTM information exchanges. These research drivers were overlaid onto the NASA statement of work (SOW) scenarios to develop a set of questions presented to UAS and USS operators.

2. Method

2.1 Participant Roles and Responsibilities

Six flight crews took part in the TCL4-Nevada flight tests. Two crews consisted of just one individual, while another two crews had approximately six members (Table 1), amounting to 26 participants who were observed and invited to complete surveys. Primary flight crew positions are listed in Appendix A, with many crew members fulfilling more than one role. Participants who served as pilot-in-command (PIC) held manned aviation flight qualifications and all flight crew participants who had roles related to operating the sUAS had previous UAS operational experience. USS software developers had created the USS software clients that were being used. They were available to assist flight crews by answering queries and helping resolve issues. Sometimes they operated their USS clients for crews during test flights while other developers operated their USS to control multiple simulated flights.

2.2 Vehicle Characteristics

The vehicles flown during the TCL4-Nevada flight tests were a variety of multi-rotor sUAS vehicles, each with varying performance characteristics and endurance limits. There were four different models of live aircraft flown (Table 1). These vehicles were able to take-off and land vertically in a small area and turn on a point in the air, which is a necessity for urban flying.

Table 1. Crew, Vehicle, and USS Client Pairings

Crew Identifier	Number of Personnel in Crew	sUAS Vehicle Flown	USS Client
GCS A	5+	AR-200	USS B
GCS C	4	DJI M-600	USS H
GCS E	1 crew (+ VO + developer all the time)	DJI M-600	USS G
GCS G	4	DA Nav-X	USS H
GCS H	1 crew (+ VO + developer occasionally)	DJI M210-RTK	USS H
GCS I	6	DA Nav-X	USS H
Sim D	1	e.g., 10 sim vehicles[1]	USS D
Sim B	1	e.g., 5 sim vehicles	USS B
Sim F	1	e.g., 8 sim vehicles	USS F

Note: GCS = Ground Control Station; VO = visual observer; AR = Air Robot; DA = Drone America; sim = simulated operations; DJI = Da-Jiang Innovation; M = Matrice; RTK = Real time kinematic.

Three of the live vehicles were controlled either through auto-flight software on a Ground Control Station (GCS) or manually by a pilot-in-command (PIC) through a handheld radio controlled (RC) unit. The PIC often launched and landed the rotorcraft manually, putting it into autopilot for the en route portion of the flight. The other three live vehicles were automatically controlled from launch to landing through the GCS's autoflight software.

2.3 Interfaces and Information Displays

Equipment available at each GCS location varied widely across the test site. At most GCSs, several displays were available to the flight crews to give them information about their vehicle's flight. Some included displays to show surrounding operations, and/or aspects of the UTM system. For example, GCS-H included four displays and a radio that were used by a single crewmember who executed all the tasks of a GCS operator (GCSO), a PIC, and a USS operator (USS Op). Standard tools on the operator displays were flight planning/execution software, a USS client on two displays, and a video feed from the vehicle. At GCS-I, in contrast, the six-person flight crew had two displays and a radio. One of those displays showed flight software and UTM information combined, and the second display was for UTM planning pre-flight.

[1] Number of vehicles simulated by each "Sim USS" varied across scenarios to give a total of 15 simulated vehicles every day across the three USS providers.

The Nevada test site provided additional weather data from stations mounted on buildings and light poles locally and offered data from Fortem radar, both of which were sent to the flight test control hub where the test director was located, to provide information about the airspace not provided by vehicles' on-board sensors. A third set of information was offered by RelmaTech, which provided localized situation awareness for the purposes of remote identification, although crews found this information useful as a situation awareness tool in general.

In the same way that there was a mix of team members and vehicle types, the five partner-built USSs also varied. UAS Service Suppliers provide services, via a client, to support the safe and efficient use of airspace, which includes communicating between elements of the UTM system, giving the user awareness of demand in the airspace to support decision making, and keeping records of flights for later inspection or data collection. These partner-built USSs that form the hub of the UTM system (Appendix B), interfaced with the FIMS (Flight Information Management System) that was hosted at NASA. The tools available within the USSs varied, primarily because each partner developed their USS independently to a set of USS-level requirements (Rios, 2017). No standards were set regarding user interface design, thus the USS developers were able to present UTM information in a wide variety of ways. The USSs were still prototype systems under development and had varying functions and features to convey UTM information to crews. To participate in the flight tests, all USSs needed to have certain basic capabilities, which they exercised in "collaboration" simulations with NASA beforehand (the Collaborative Simulation took place in April 2019), but the manner and extent by which the partners met those requirements differed.

2.4 Test Scenarios

The test aims were presented in the NASA statement of work as five scenarios encompassing 39 characteristics (CH) and 16 test events (TE) that, when combined, were designed to portray different use cases for sUAS in complex environments (Rios, 2018), e.g., CH1 was a percentage of low density operations at 3 or fewer aircraft per 0.2 square miles, and TE1 was operations impacted by a dynamic restriction. The scenarios featured 15 simulated vehicles, multiple live vehicles, and multiple USSs. These scenarios followed and expanded on most of the characteristics from the National Campaign flight tests of 2017 (Martin, et al., 2018) and the TCL3 testing of 2018 (BVLOS operations, dynamic re-planning, responses to alerts from the UTM System, and the implementation of off-nominal contingency plans) and added characteristic functions like negotiation, UVR (UAS volume restriction) placement, and priority status (Martin, et al., 2019).

NIAS agreed to undertake meeting the criteria for, and flying, three of the five sUAS scenarios from the NASA SOW, which included 31 characteristics and 12 events. These scenarios were designed to focus on incoming weather (scenario 1), an incident at a large group gathering that required emergency response (scenario 2), and large-scale CNS issues (scenario 4). Detailed descriptions of the three base scenarios and their corresponding characteristics and events can be found in the TCL4 statement of work (Rios, 2018).

With the directions given in the SOW (Rios, 2018), NIAS interpreted the NASA scenario briefs and created their own detailed test scenarios to explore the use of UTM in the Reno, Nevada urban environment (Brilliant & McGuire, 2019, proprietary, document not available). Two scenarios (1 and 4) were located directly downtown, in an environment characterized by multi-story, closely-packed buildings (as most downtown city areas are), see Figure 1. The NIAS scenarios defined activities for 15 simulated vehicles, five live vehicles, and five USSs, resulting in multi-volume flight operations, and dense spacing near obstacles and people. Bases of operations (Ground Control

Stations, GCS) for live flights were located at here-to-fore untested landing zones, including roof tops, on city streets, and in empty urban lots.

Figure 1. Example of the Reno urban environment—the downtown city center.

Scenario 2, which was run third, was located in a Reno urban park. This environment has few buildings but more dynamic obstacles like trees, wildlife, and power lines (Figure 2). NIAS defined activities for 15 simulated vehicles, five live vehicles and four USSs in this environment. Ground control station locations for live flights were in grassy park areas and open spaces but always close to smaller obstacles: trees, fencing, and flag and light poles.

Figure 2. Example of the Reno suburban environment, a city park.

Due to the logistic constraints of shutting down some city streets for a number of days, operators at the Nevada test site executed each of their three scenarios wholly and consecutively, i.e., completing one scenario before moving on to the next. This resulted in an order effect, scenario 1 took place during the first week, scenario 4 was at the beginning of the second week, and scenario 2 was at the end of the second week. Thus, crews were more familiar with their vehicles, the environment and with their USS for scenario 2 than for scenario 1. There were also environmental differences between the scenarios. As noted, scenarios 1 and 4 took place downtown, scenario 2 took place in a park, which, while still an urban setting, had fewer obstacles that were buildings, and less vehicular and pedestrian traffic, but more trees and powerlines. These differences added richness to the data, but it should be noted that pilot concerns were different for scenarios 1 and 4 versus scenario 2.

2.5 Research Objectives

With the goal of instructing what the minimum information requirements and/or best practices might be in TCL4 operations, the driving enquiry was: How do UTM tools and features support (human) operators leading to safe and effective conduct of large-scale BVLOS sUAS operations in "urban canyon" environments? This enquiry touches on one measure of performance (MOP), one measure of effectiveness (MOE) and two USS requirements set out by (SOW, Rios, 2018; MOPS document, Rios, 2019). UTM MOP #15 states that the TCL4 research effort should provide feedback on: Pilot assessment of UTM information properties (MOP, Rios 2019, sheet 1) and UTM MOE #4 advocates investigation of the statement that: UTM allows for common situational awareness of the airspace and operations within it to support sUAS operations (MOP, Rios 2019, sheet 2). At a different level of enquiry, USS requirements #5 and #6 state that: the USS shall provide human interfaces to operators and ensure that the human interfaces are appropriate to support testing activities (SOW, Rios, 2018, page 23). These two UTM measures and two USS requirements were re-interpreted from the user's point of view to state that the UTM system needs to:

- share information with users (through a USS client)
- provide adequate crew situation awareness (SA)

For UTM information to be usable, operators need to have enough knowledge in order to:

- understand what they are seeing both in the airspace and on the GCS
- be able to respond quickly and appropriately enough to the information when an action is needed

Five main attributes that indicate users' ability to operate safely and effectively within UTM were considered in the data collection at the Nevada test-site: situation awareness (SA), risk perception, communication, confidence/ trust in tools, and response quality (Figure 3, green box).

- The user should have good situation awareness; the ability (based on training) to understand the UTM information they have access to, about their operation, and about the environment. In turn, these information items are sufficiently usable, salient and intuitive.
- The user should have good risk perception and a high level of safety awareness; the ability to differentiate between varying levels of risk of an operation and make decisions based on their assessment. The information available should have properties that make it support risk management.
- UTM system-to-user communications should be good; communications (messages, notifications, alerts) received by crews are understandable. Communications are sent at the right time for users to be able to make use of them.
- User confidence and trust in UTM should be high; users are able to base their decisions and actions on UTM information alone, but are also able to consult

(multiple) other sources if desired. Information is reliable and accurate enough to inspire trust.

- Efficient and effective user responses to UTM information; users are able to act effectively through the UTM system. Action options are available and functional.

These five attributes represent successful user-system interactions from the user's point of view and were used to guide the organization of comments from debrief discussions and observers' field notes (Appendix C).

In order to promote these types of successful user-to-automation interactions (HSI), the UTM system (especially its interfaces, mainly in the form of USS clients) would benefit from having a number of properties, some of which are listed in the peach hexagon in Figure 3. Thus, some questions on the surveys and during the debriefs were asked from this point of view—how well users thought the UTM system and the USS clients worked, and whether the functions needed in both were present.

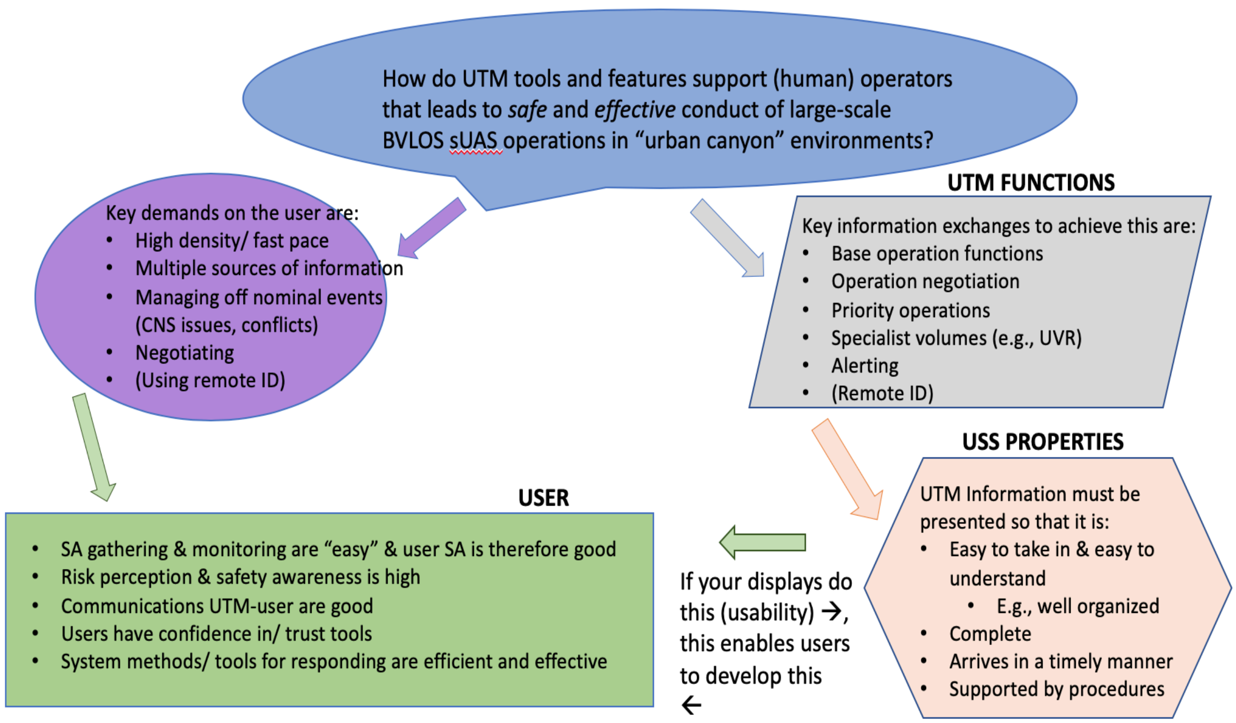

Figure 3. Research question and information topics used for organizing qualitative data collected.

While the key focus of the enquiries described below is the user's experience, critical to the success or failure of this experience is the UTM system and, in particular for TCL4, the USSs as these provided the interfaces for users to interact with and view the UTM system. USSs perform many functions and a subset of these requires the user to be aware of, and in some cases take part in, the functions being executed. Functions that are in this latter category, and were of particular interest in TCL4, included priority operations, managing UVRs, conflict avoidance, and dealing with CNS issues (grey parallelogram in Figure 3). User-UTM (human-system) interaction is facilitated if interfaces have a number of properties, including being easy to understand, providing information at the right time (usually quickly enough) and providing all necessary information (peach hexagon, Figure 3). Additional features that improve usability are being straightforward or intuitive to operate when the user needs to interact with the system and having clear procedures for those actions. These features of USS interfaces, when successfully implemented, enable users to develop situation awareness, develop confidence in the tools, and have a calibrated perception of risk, etc. (green rectangle, Figure 3).

2.6 Data Collection

The TCL4 flight demonstration at Reno, Nevada took place during ten days in June 2019. Prior to the test flights, there were ten skill development and practice days run at Reno-Stead Airport during May 2019, and four official shakedown (i.e., 'practice') flying days, on location, in the Reno city center also during May 2019. Flight crews were comprised of individuals from partner organizations and, in the case of most teams, traveled to the Reno test site for the duration of the testing. Some of these organizations developed USS clients, while other partner organizations focused on drone operation and teamed with another partner that provided USS support. There were four USS-developer partners who teamed with partner flight crew organizations to take part in the flight tests, totaling 14 partners working with the NIAS organization[2].

Over the course of the 10-day Nevada flight test, 28 data-collection runs were flown: eight runs of flying for the events in scenario 1, nine for scenario 2, and eleven[3] for scenario 4. Across these 28 scenario runs, 1,222 operations were submitted, of which 318 operations (e.g., Figure 4) took place as data-collection flights—247 of these were simulated flights and 71 were live flights (Table 2). The approved flight polygons were represented on USS clients and are referred to here as "volumes."

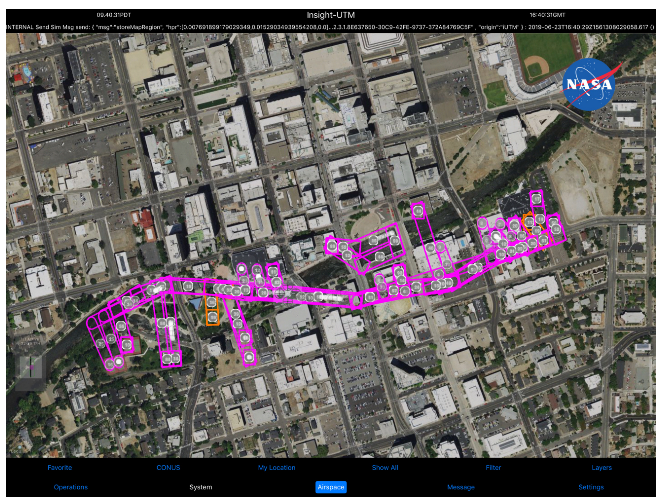

Figure 4. Example of complex urban fights over downtown Reno, showing both live and simulated operations and their volumes, with more than one USS contributing. Note: Magenta polygons are active volumes, operations are rogue in orange polygons. The position of airborne UAS are denoted by solid white dots.

During the ten test days, two teams of researchers from NASA's Airspace Operations Lab (AOL) collected data from participants in the field at the Nevada test site. In the NASA AOL observation rooms, a team of UTM developers verified data flowing through the system and a small team of AOL researchers remotely collected data on the test scenarios. The main data-collection team was in Nevada with the flight crews during the testing. During the first week, a team of four was present,

[2] The City of Nevada also participated in the flight tests as they provided law enforcement and fire crew personnel to assist with traffic management but are not included in this count.
[3] Not all crews flew vehicles in scenario 4.

and during the second week a team of six were on hand to collect data. Data were collected in a number of ways:

- through observations of the participants during flights
- through a counting app where observers counted crew interactions with their USS clients (see Appendix D for a summary of these data)
- end-of-day surveys
- end-of-day group debriefs

These data-collection methods were included in the DMP (Data Management Plan, Modi, 2019) that was constructed to inform and assist test sites with their data-collection process.

Table 2. Number of Live and Simulated Flights providing Data for the TCL4-Nevada Fight Test

	Scenario 1	*Scenario 2*	*Scenario 4*	*Totals*
Live flights	23	37	11	71
Simulated flights	43	78	126	247
Total operations	66	115	137	318

Note: Only operations with at least 120 position reports have been included.

All of these methods solicited feedback on the five areas of interest for these tests (Figure 3). In total, 57 crew surveys (an additional seven mission surveys), 11 runs of counting app data, and nine end-of-day group debriefs were collected.

Debriefs. During these end-of-day debriefs, flight crews discussed their experiences interacting with the UTM system, specifically their situation awareness and communication. Questions were framed in terms of the scenario that had been flown and were approached in terms of the UTM functions teams had experienced during that day.

Counting application. The instances of crews receiving and using UTM information for four UTM-specific types of events that needed to be communicated through the crew were recorded through a counting application. Researchers counted how, and when, instances of this type of UTM message was communicated[4] to the crew.

Survey. Survey items were generated with the five user-topics (Figure 3, green rectangle) in mind, and were presented to the participants in the context of the scenario flown for that day, therefore addressing the functions that they had had an opportunity to use. Approximately 75 questions were generated across three surveys, but conditions were set so that participants only answered around 25 at any one time. Most questions used a seven-point rating format, with 7 representing a very positive rating and 1 representing a very negative rating. Some questions were multiple choice or open-ended. Researchers in the field also took notes while they were watching flight tests.

[4] Flight crews may have received the same items of UTM information from multiple sources (e.g., USS client, radio, and CO). Researchers coded the primary source of the UTM information in this case.

<u>Operational data</u>. Operational data (e.g., logs and position reports) were provided by, and collected from NIAS and their partners, but these data are considered elsewhere in other reports. Following the way questions to users were organized, participants' experiences are first described below associated with the UTM information exchange that prompted the experience, and then the ways in which that interaction, of user with UTM information, could be improved are outlined.

3. Results

3.1 UTM Function: USS-to-USS Negotiation

USS-to-USS negotiation is a means by which flight operations can occupy the same airspace for a short amount of time. To achieve this intersection of airspace, both operations are required to agree to the potential to negotiate in advance and must have the same priority level. For TCL4, there were two "flavors" of negotiation available: re-planning or intersection. For the first, accepting negotiation would require one operation to re-plan its volume; and for the second, an accepted negotiation meant both operations could occupy the same volume for a short time as one operation is in transit past another. Two scenarios in TCL4-Nevada (scenarios 1 and 2) required USS-to-USS negotiation (see SOW, CH 25–31, Rios, 2018), where operation volumes for two UAS were going to intersect and the USS client had to coordinate both vehicles safely moving through the airspace/volume.

There were 862 negotiation agreements through the UTM system during the TCL4 Nevada flight tests. By far, the majority of negotiation agreements were for intersections (829 [96%]), broadcast through over 7,000 messages and only a few re-plan agreements (33 [4%]), broadcast through over 200 messages (Appendix F). Observers counted crews' use of information about negotiation from both UTM and other sources, recording it in their app. There were 18 counts across two of the three scenarios (Figure 5). Counts showed that, in scenario 1, 78% of the negotiation information shared through the crew (n = 7) was first received through a UTM source, whereas in scenario 2, 89% of the shared negotiation information (n = 8) was communicated first through other sources (e.g., over the radio).

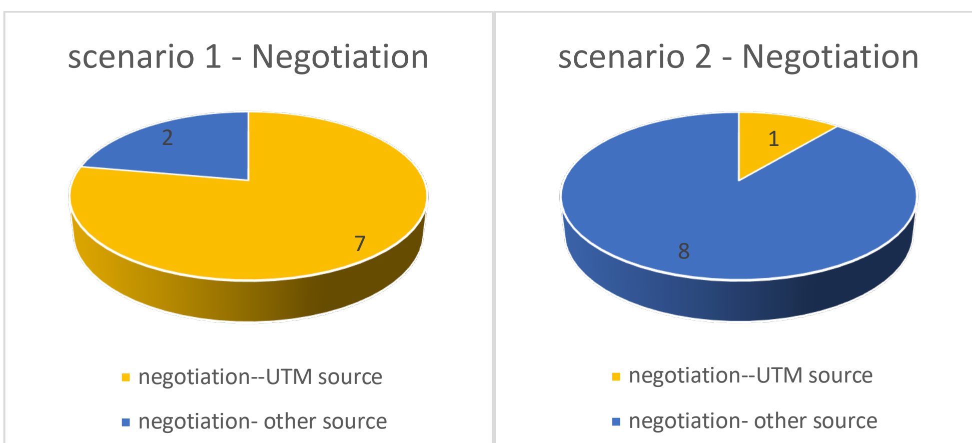

Figure 5. Observation count of items of information received about negotiation during flights, n = 18.

There was some confusion and gray area within the existing protocols for negotiation, which led users to question requirements, limitations, and status during negotiations. There were several suggestions for adding standard USS settings that would inform how an operation might react to a negotiation in the future. Crews reported that their insight into the USS-to-USS negotiation process was not particularly clear. Not having a window into the negotiation process left crews with two major concerns 1) that they might always be the "loser" in negotiations and that the system may be inequitable, and 2) that a negotiation that does not consider future impact may put the user into a series of negative situations for the rest of their flight (e.g., conflicts). A number of crew and observer comments support this summary.

3.1.1 Participant and Observer Comments

Users noted that the negotiation protocol was unclear to them. In one example, users cited confusion when their operation was not accepted through UTM but did not know why, as they did not receive feedback. In this example, the proposed negotiation was rejected by the other USS operator, but no indication of the rejection was provided to the user. In the online survey, respondents indicated that they would like to be involved in the USS-to-USS negotiation process regularly, but not all the time (Appendix E, Figure E1, $\overline{x}$ = 3.76, σ = 1.6, n = 34). In their comments, respondents focused on the effect of negotiation, indicating that they need to be informed of the outcome of negotiation and reasons for the outcome. Half of the respondents wanted to know about negotiations if they resulted in an intersection with another volume, and a quarter wanted to know if the negotiations resulted in negative consequences for their operation.

The system does not have clear incentives that would persuade a user to agree to re-plan. There were concerns about other users ignoring negotiation outcomes that are unfavorable to them or gaming the system, assuring that they "won" negotiations. Currently, with low insight into the negotiation process, users were often unaware of the impact that their negotiation had on others' operations. The low visibility into the process led to other concerns as well. Operators were concerned that if many negotiations were requested on a flight and they always agreed to alter their flight plan to accommodate others, that their situation awareness of their flight plan may become compromised. They were also concerned that an unfortunate negotiation could put their vehicle into a conflict situation or into a position that required negotiation with a third vehicle. They suggested that the USS-to-USS negotiation process should take the number of previous negotiations and also the future impact of negotiations into account as the system determines a negotiation outcome.

Crews noted that a good USS interface would give them visibility into negotiations and highlighted the fact that the current prototype USSs do not have a complete negotiation interface. Users discussed needing a wider range of settings where they could indicate their negotiation preferences and even the ability to set ranges within these settings.

Users pointed out that there is an interaction between negotiation and flight priority. Participants argued that a flight that has priority status (e.g., due to a system failure) should not have to negotiate and should be allowed to fly through others' space (as is the case currently in the UTM system). In effect, a priority flight would "win" every negotiation it encounters. However, this leads to two arguments. First, participants questioned which priority flights have greater priority, suggesting that there would need to be a somewhat detailed listing or description of which types of operation would have higher priority than others, clarifying who would have the advantage in a negotiation situation. For example, if one priority flight was a medical flight and a second was a UAS with a low-battery alert, which of these two flights should have higher priority and therefore avoid negotiation?

Second, users debated about the speed of negotiations within the system and avenues for action if the airborne UAS reach proximity before the UTM system has completed the negotiation. One example would be a vehicle that is returning home directly due to an on-board issue. They queried whether a set of procedures should be set out that gives one of the vehicles the right-of-way in cases like this where there is not time for negotiation.

Responses to survey questions about *negotiation* support the comments above. Respondents indicated that they did not receive enough information about negotiation from their USS interfaces ($\bar{x}$ = 2.58, σ = 1.3, n = 29; Figure 6), that negotiation alerting was ineffective ($\bar{x}$ = 2.95, σ = 1.7, n = 24) and that negotiation outcomes lacked clarity ($\bar{x}$ = 3.03, σ = 2.2, n = 27), although ratings for effectiveness of alerting were, on average, a little higher for scenario 1 than scenario 2 (no significant differences when tested using a t-test).

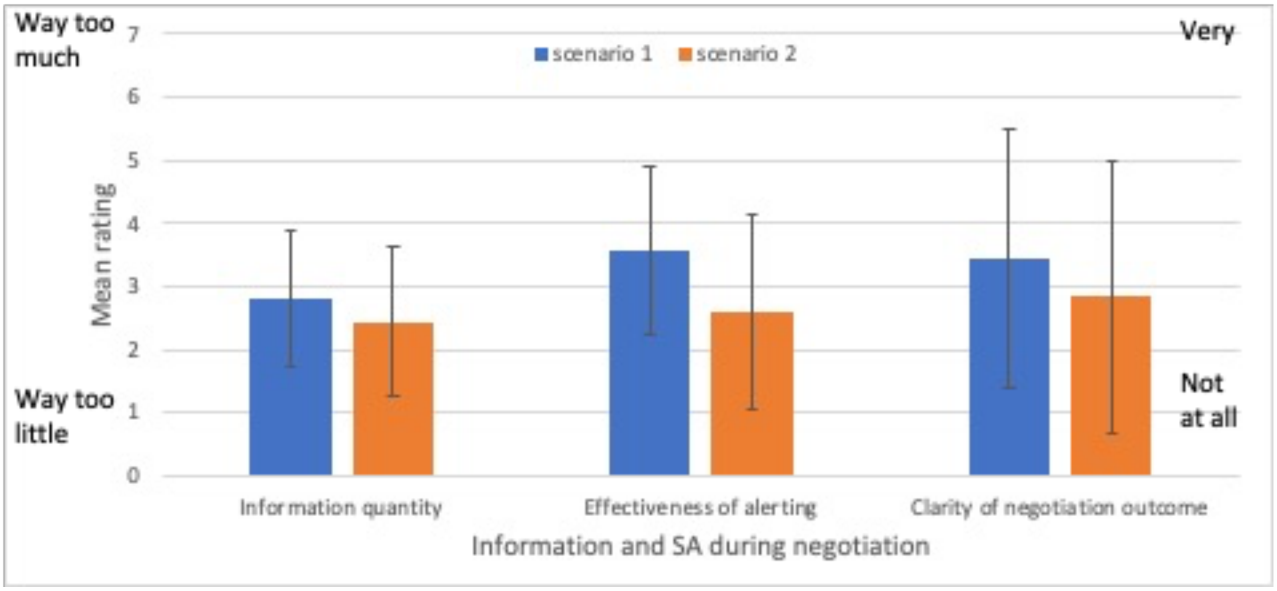

Figure 6. Participant opinions on information received about negotiation within UTM, it's quality, the effectiveness of alerting and clarity of outcome. N-quality = 29; n-effectiveness = 24; n-clarity = 27, 1-7 scale extended to show full standard deviations.

3.1.2 Requisite Properties Within UTM for USS-to-USS Negotiation

Exercising and observing USS-to-USS negotiation events in TCL4 prompted participants to discuss their awareness of negotiations and suggest improvements for the information shared about USS-to-USS negotiations. Given the results above about the lack of clarity reported for the rules and processes regarding UTM negotiation, properties to improve are:

- define procedures for negotiation operations
  - set conditions for accepting or rejecting negotiation requests
  - define methods that prevent "gaming" the system
  - establish a clear order of priority for negotiations that is available to the user

These properties would support crew situation awareness, increase user trust, and improve the efficiency of the system through UTM communications:

- UTM messaging is more transparent if it clearly shows the
  - operator's selection of negotiation conditions
  - states/outcomes of those negotiations

These properties would support crew situation awareness and increase user trust.

3.2 UTM Function: UVR Management

A UVR (UAS volume restriction) is one example of a dynamic restriction and a UTM constraint. In TCL4, UVRs worked in a way similar to a controlled airspace Temporary Flight Restriction, denoting a volume of airspace that has restricted entry criteria for some period of time, for safety reasons or because specialists need to use the space. UVR flight-restricted areas were put up in scenarios 1 and 2 (see SOW, TE-1, Rios, 2018). In scenario 1, the UVR was to denote an area of incoming weather (area with blue border in Figure 7a), shutting down the area to all airborn vehicles for safety reasons. In scenario 2, an incident on the ground, requiring response from law enforcement and safety personnel, led to a UVR being put in place (Figure 7b), allowing the first responders' UAS unhampered operating space.

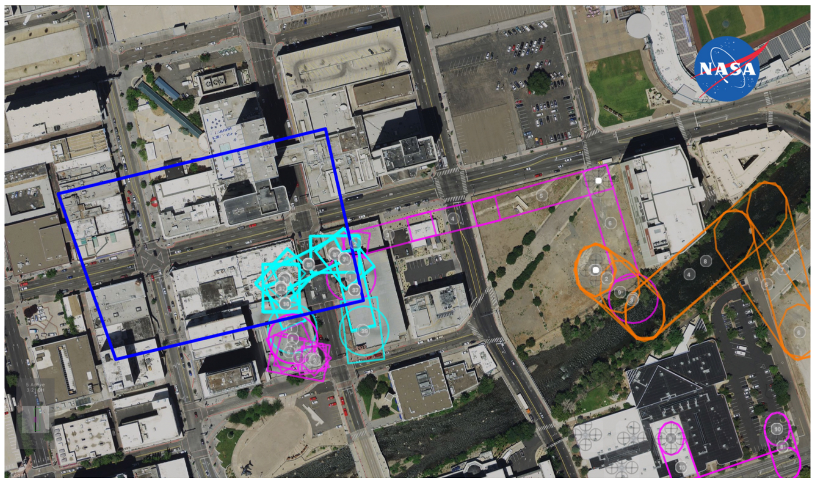

Figure 7a. Example of weather UVR put up during the Reno, Nevada, scenario 1. Weather UVR is denoted in royal blue; magenta, cyan and orange volumes are flight volumes.

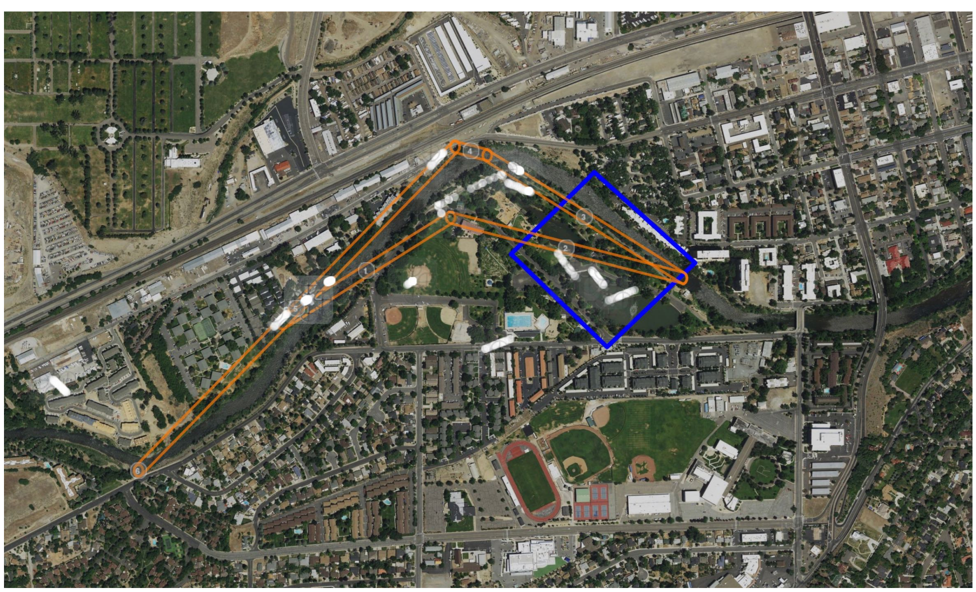

Figure 7b. Example of an event UVR put up during the Reno, Nevada, scenario 2. Event UVR is denoted in royal blue; orange volume is a flight volume showing rogue; white dots are vehicles.

There were 24 UVRs[5] established at the Nevada test site during TCL4 testing, with over 40 messages sent to broadcast those UVRs through the UTM system. These 24 UVRs were dynamic restrictions (see Appendix F for more details) put into effect during both scenarios 1 and 2. AOL observers counted crews' use of information about UVRs from both UTM and other sources. There were 38 counts across the two scenarios where UVRs were posted (Figure 8). Counts showed that in scenario 1, where the event was weather, 80% of the UVR information shared throughout the crew (n = 4) was first received through a UTM source (e.g., USS) and, similarly, in scenario 2, the incident at the concert, 79% of the shared UVR information (n = 26) was first communicated through UTM, indicating UTM was the primary source for UVR information.

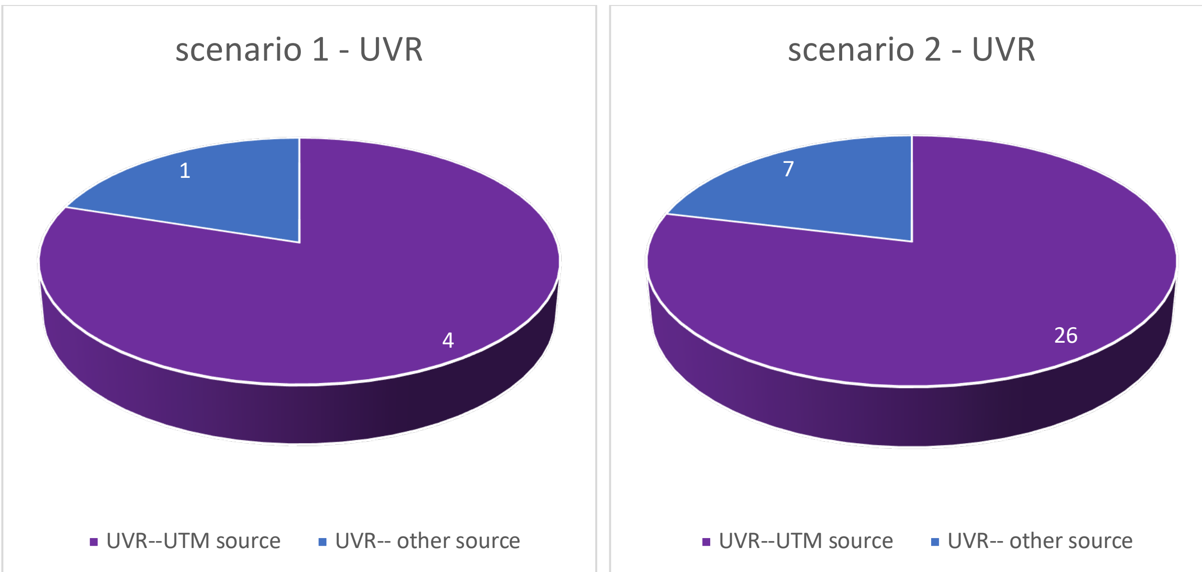

Figure 8. Observation count of items of information received about UVRs within flight tests, n = 38.

Discussions at the time the UVR was posted during the run centered around what information was available to crews about the UVR as it came into place and the conditions that initiated it, especially those relevant to a crew's own operation. Discussions emphasized the need for a common understanding of UVRs and a number of crew and observer comments support this summary.

3.2.1 Participant and Observer Comments

Participants reported the UTM information they had available about the UVR "somewhat helped" their awareness of the airspace ($\bar{x} = 4.41$, $\sigma = 2.0$, n = 24) which is supported by ratings of the UVR information as reasonably reliable, trustworthy and accurate (Figure 9).

In both Scenarios 1 and 2, participants reported they had good awareness of their own operation's location ($\bar{x} = 5.57$, $\sigma = 2.1$, n = 28) and volume ($\bar{x} = 5.25$, $\sigma = 1.9$, n = 27) while the UVR was in effect, and a reasonable awareness of their UTM state ($\bar{x} = 4.76$, $\sigma = 2.2$, n = 26) (Figure 10). The difference between participants' opinions of their volume awareness was significant between scenarios when tested using a Students t-test ($t = 1.982$, $df = 7$, $p < .05$) suggesting participants felt more aware of their operational volume as the UVR became live during scenario 1. While participants reported the UVR information was more helpful and of better quality in scenario 2, they

[5] UVRs needed to exist for 60 seconds or more to be included in the data considered.

reported slightly lower awareness of their vehicle's parameters. In general, participants requested more UVR information, including whether or not a user is allowed in a UVR, clear visibility of intersecting volumes for context, better knowledge of the environment (particularly incorporating better z-axis information), and that additional details (location, altitude, callsigns) be displayed clearly and in one place.

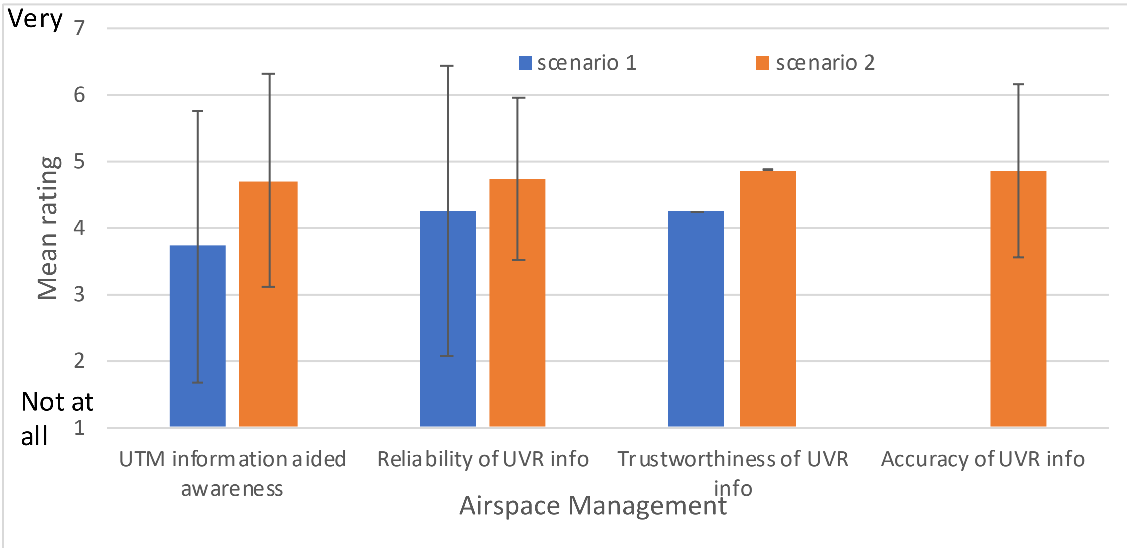

Figure 9. Participant-reported opinions about the quality of available UVR information. N-aided awareness = 24, n-reliability = 18, n-trustworthiness = 18, n-accuracy = 14, 1-7 scale "not at all" to "very."

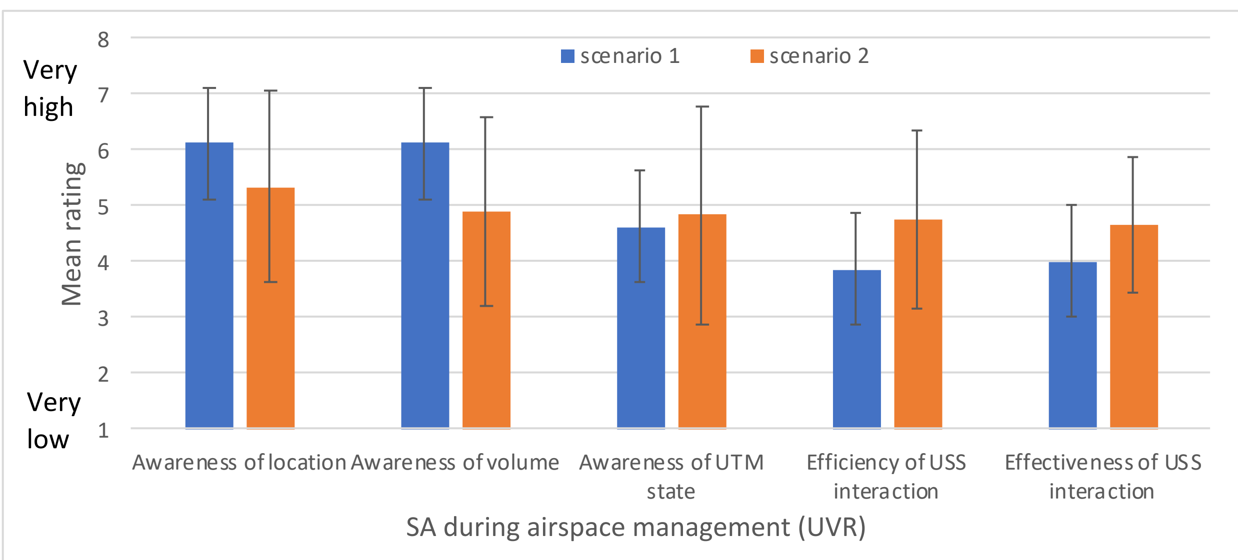

Figure 10. Participant ratings of awareness of flight properties (location, volume and state) and the quality of the interaction (efficiency and effectiveness) with the USS during UVR activation, n-location = 28, n-volume = 27, n = state = 26, n-efficiency = 23, n-effectiveness = 21, 1-7 scale extended to show a full standard deviation of responses.

When asked, users wanted to see more information with respect to the UVR event. In particular, operators stressed that the USS must send a clear message to all operations involved, detailing whether or not they are permitted within the UVR and when they can and cannot enter the UVR, i.e., the message that "yes, you are authorized" or "no, you are not authorized" is extremely important. This was emphasized by users who received notifications that lacked necessary information and therefore, were ineffective. For example, one USS did not show a message or information naming the event as a UVR, but rather as a conflict between the operation's volume and another volume (the UVR), which is technically correct but does not include meaningful context to help users take appropriate action. In another example, a crewmember described how their vehicle went rogue on entering a UVR but the UVR boundary was not displayed on the operator's interface to explain why their vehicle was rogue.

Crews suggested a variety of interface elements through which this information could be displayed, including labels, pop-up windows, and messages. The most common request was a visualization of UVR volumes, with clear labeling (see Arbab, 2019) for a discussion of interfaces and their requirements). One suggestion was that there should be a standard display for UVRs, so that no matter which USS an operator looks at, the UVR information can be found in the same way.

Crews did acknowledge there could be data saturation from UTM/their USS due to the amount of information that could potentially be presented with a UVR. Crews discussed management of information to prevent overloading the user. Participants said they want to be informed about rogue aircraft in a UVR, but would not need to know about priority aircraft that are allowed into that volume.

Pilots emphasized that knowing about the UVR itself was very important, especially if the UVR was going to encompass or overlap their volume. The reasoning for needing this level of information is that when a UVR is put in place, an operator needs to decide their course of action. They need to consider whether they should go around the UVR, or loiter until it expires, and whether they have enough fuel to take either option. One issue that made this decision impossible for some crews was that they did not have deviation capabilities in their USS, meaning they could not re-plan in response to the UVR. Another issue that made managing UVRs difficult was USSs that do not publish the operational globally unique flight identifier (GUFI), as without the GUFI information, the USS that was publishing the UVR could not give access to the operation with "no GUFI." These crews emphasized that USSs need to have functionality that enables users to avoid the UVR or divert. One crew noted the broader need for more functionality in their USS, especially the ability to change their operation plan if something unexpected occurred while they were airborne and they called out a UVR event as an example. As they were unable to change their flight plans while in flight, they were unable to react to the UVR. However, crews did note that for UVRs, their knowledge could be localized. If the UVR covers a large area they do not need to see the whole space, just the part of the UVR that encompasses or touches their volumes and other volumes that are close by, and information on whether it impacts them. This implies that there needs to be a way to show that a very large UVR is in place without showing the entire UVR.

While public safety officers noted they would want to see all the operations within a UVR, both non-priority crews and public safety officers agreed that non-priority users would not need to see complete information about other users, including access permissions (allowed/ not allowed), only their own.

3.2.2 Requisite Properties Within UTM for UVR Management

Although crews used the majority of the UVR information they received, observers noted that UVR interfaces did not give the user enough information. There was a lack of clear visual notifications and a lack of written information (via messages). Despite this, researchers observed examples of crews sharing awareness of the parameters that drive UVRs within UTM and awareness of their operation's location and status relative to the UVR. However, they also found examples of crews who lacked awareness of UVR parameters and how to react to a UVR becoming live around their volume. Crew feedback was focused on situation awareness (SA) – and the need to be provided with enough information to understand why the UVR had been established, the nature of the restriction, and how they, as the user, can adhere to the new restriction. Unless they were first responders, crews did not want to know who stayed in the UVR. Taken together, these comments suggest that:

- More information than is currently available through UTM needs to be provided to users and the requirement to provide these items needs to be clearly stated.
  - Ordinary users need a clear permitted/not permitted in the UVR message.
  - All users need a clear, standardized depiction of the UVR and its state (e.g., proposed, active, etc.).
  - Priority users need awareness of other operations in the UVR.

These properties will improve human-system communication, support crew situation awareness, increase user trust and help users to operate and act as UTM (and other users) expects.

- Provide UTM information and messages that are more complete and that *clearly* define the:
  - UVR and its parameters.
  - operator's permission status with respect to the UVR.
- USS functionality that enables crews to respond to a UVR.

These properties will support crew situation awareness and increase user trust and help users to operate and act as UTM (and other users) expects.

3.3 UTM Function: Priority Status

One property that was touched upon in both negotiation and UVR discussions was a user's UTM status. Within UTM, users can gain a priority status, which elevates their ability to access airspace. There are two types of priority status: for a role that requires access, typically public safety or first response, and for operations experiencing an emergency, e.g., due to a low battery, mechanical fault, or issues with CNS. The first responder priority status may be designated when an operation submits a first response mission, and it will remain designated for the whole operation. The emergency priority status is a temporary designation, issued only when an operation declares an emergency, and lasts until the vehicle can reach a safe landing location. Two scenarios in TCL4-Nevada (2 and 4) involved priority vehicles; in scenario 2, priority was granted for special access to the UVR and in scenario 4 priority was granted due to reduced vehicle capability (see SOW, CH-8, Rios, 2018).

Observers counted how often crews used information they received about priority operations from UTM and other sources. There were 18 counts across the data-collection period. In both scenario 1 and scenario 2, priority status information was received through UTM half of the time and through other methods (e.g., radio) the other half of the time (n = 8) (Figure 11). In scenario 4, priority status information was always received through a source other than UTM (n = 10). Participant reports indicated that, in some cases, the issue was timing of information. In the crew survey, users reported that information about another vehicle's declaration of emergency priority arrived through UTM at close to the right time but verged on a little late ($\bar{x}$-self = 4.33, σ = 2.1, n = 9; $\bar{x}$-other = 5.16, σ = 2.7, n = 6; Appendix E, Figure E2) for them to take useful evasive action.

Participants noted that when *they* had to make a contingency maneuver and assume priority status, the message that came through UTM was "clear" during scenario 2 but "not clear" during scenario 4 (Appendix E, Figure E3), although the low number of responses for scenario 4 may have skewed the mean. The second part of the process, when they had to indicate their action intentions as a result of having an emergency, was reported as an acceptable process ($\bar{x}$ = 4.22, σ = 2.3, n = 9). In addition, crews reported they were "moderately confident" in the accuracy of the information coming through UTM about others' priority flights ($\bar{x}$ = 4.1, σ = 2.3, n = 10), although these ratings are possibly influenced by the perceived clarity of messages.

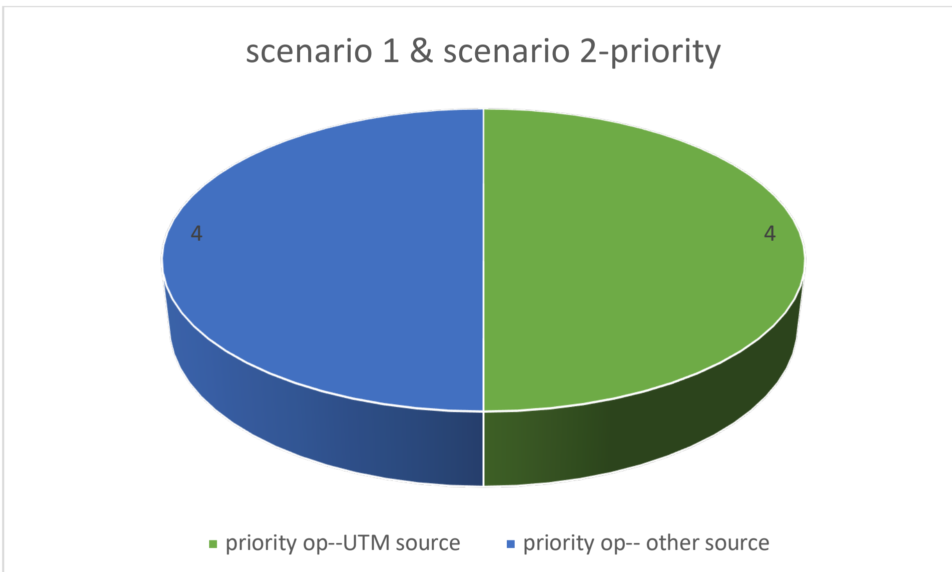

Figure 11. Observer count of items of information received about priority flights for two data-collection scenarios. N = 18, scenario 4 data not charted.

3.3.1 Participant and Observer Comments

Users were confused about levels of priority. They were aware that there were different levels of priority but were not sure how these were allocated or why. Debrief discussion covered this and explored whether it would be useful to have a defined list of situations or properties which determine operational priority.

As an example, users noted that levels of priority were not clear. For example, one crew did not understand that announcing they were an emergency priority flight (when flying a low battery and emergency landing scenario event) would change their status temporarily to "priority," which would help them in their return to launch (RTL) and give them temporary exception within UTM to fly directly to base. The crews who did understand this feature confirmed that some USS functionality was very useful, such as the ability to receive temporary priority status if the operator has a failure/emergency that could then allow the USS to build volumes in airspace that the operator had not previously defined. This underlines that the guidelines for how an operation could be assigned priority status was not clear to all of the TCL4 participants. In addition, crews were unsure whether a USS could distinguish priority status from nominal operations. During debriefs, crews debated how to simplify and clarify priority status guidelines, stressing that the rules need to make it easy for users to determine their own status and those of other vehicles. Easy recognition would allow operators to make decisions about their actions, e.g., whether to proceed into/ within the UVR area or to vacate that space.

There was also some uncertainty when crews needed to give way to other vehicles that had priority status. First, it was not clear to them which vehicles had priority status and were exempt from the RTL rule when a UVR came into place. Second, users were not always certain when a vehicle that had an emergency-priority was flying through or close to their volume, and they commented that they needed clear and direct messages to inform them so they could respond appropriately.

3.3.2 Requisite Properties Within UTM for Priority Status

Crew feedback centered around wanting clarification of the guidelines that determine priority status and also improving the quality of priority messages.

- More information than is currently available needs to be provided to users:
  - Ordinary (non-priority) users need clear messages about when a priority user will be in or near their volumes.
  - Ordinary users need clear guidance (possibly notifications) about priority user actions that are acceptable as a priority flight but not as an nominal user.
  - A clear means of indicating a vehicle has priority status.

These properties will support crew situation awareness and understanding, raise user confidence in the UTM system, improve operator communication and increase user trust.

- Clear UTM guidance needs to be provided that details:
  - How priority users are determined.
  - When priority status applies.
  - Tte UTM guidelines that priority users are exempt from and those which they are not exempt from.

These properties will support crew situation awareness, increase user trust in UTM and improve compliance with UTM guidelines.

3.4 UTM Function: Remote ID

Remote identification (RID) is the process by which a third party makes a query for key identifying details or information about an operation. There are a number of ways this can be done, either through the UTM system or through independent software, such as an SDSP. The first steps toward a RID function were offered both in and outside of UTM at the Nevada flight tests. Small radio broadcasting units enabled the RelmaTech company to complete UAS position locating through vehicle-to-vehicle (V2V), and display the results on an application that was not connected to UTM. Operators at the Nevada test site also tried running identification queries through the UTM system, testing both methods in scenarios 2 and 4 of TCL4 (see SOW, CH 34-37, Rios, 2018).

Half of the participants, who participated in and were asked about remote ID events, said they were not aware that RID had occurred during the scenario. Of those who were aware, most heard about the RID over the radio or person to person and only one person confirmed they saw the RelmaTech app during the scenario (Figure 12). However, debrief comments indicate that more than one person saw the V2V app, and that they did use it to increase their situation awareness. One crew member noted that details of other operations (location, altitude, callsign) were missing from their USS display but they could see these things on the RelmaTech app, which they used to guide them about when to contact other crews for deconfliction.

Participants were divided about whether they wanted to see RID queries as they were made, with 40% agreeing they wanted to see remote ID queries. Participants were clear that when RID information is shown, it should be displayed through UTM.

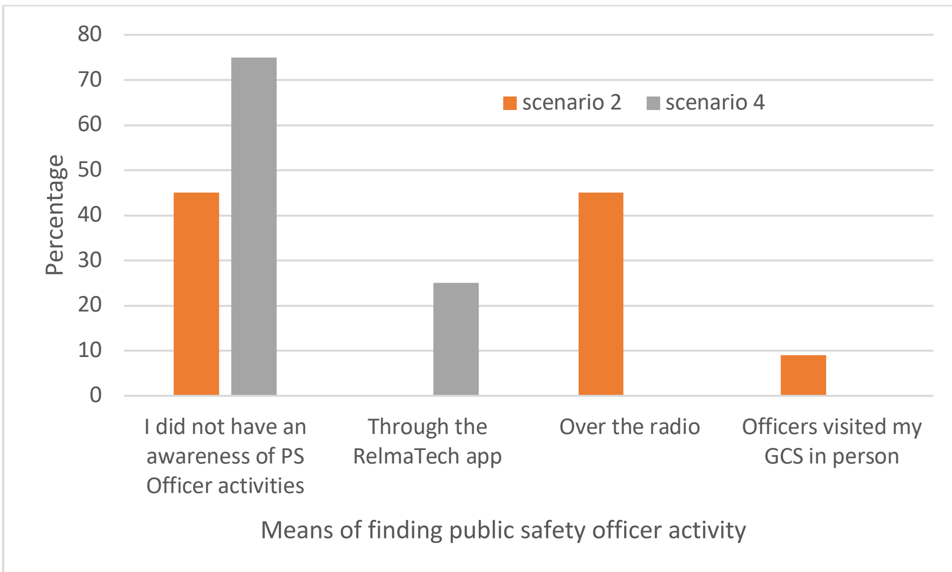

Figure 12. How participants became aware of public safety RID activities. N= 15.

3.5 UTM Function: Indication of Conflicts, Conflict Alerting

A central function of the UTM concept is for a USS to alert users when their volume is breached by another operation and to alert the blundering operation that it is out of its own volume. The USS implementations did not suggest solutions to the conflict for this test, their role was to alert the teams involved that there was an issue. Although there were conflict events in all three scenarios at the Nevada flight tests, on some days during scenario 4, the conflicts were simulated because too few live aircraft flew for live conflicts to occur (see SOW, TE-5, 8, 9, Rios, 2018).

Crews responding to survey questions reported that their USS client was "not particularly effective" ($\overline{x}$ = 3.2, σ = 1.9, n = 15) in alerting them to an impending conflict (Figure 13). However, their opinions varied across scenarios with crews rating USS alerting as "somewhat effective" during the urban canyon scenarios and "not effective" during the park-area scenario 2 (see Figure 13). Correspondingly, respondents' opinions of whether they were able to maintain awareness of vehicles near their own operation, and thus to avoid them, also varied by scenario. Crews reported they were able to maintain awareness reasonably well during scenario 1 ($\overline{x}$ = 5.3, σ = 0.98, n = 12) but not nearly so well (on average) during scenario 2 ($\overline{x}$ = 3, σ = 1.9, n = 10). When compared using a

Students t-test, participants' ratings of their awareness of conflicts during scenarios 1 and 2 were significantly different (t = 3.371, df = 11, p <.05). Participants may have found it more difficult to maintain awareness during scenario 2 because the conflict alert did not seem as effective.

Some participants reported having seen UTM conflict messages, supporting that these crews had some awareness of the conflicts in the system (Appendix E, Figure E4). When they noticed conflicts, crews reported they used the radio to draw the attention of the other crews involved and discuss a resolution. However, the proportion of participants reporting that they did not see any conflict messages (40%) suggests that USSs were not reviewed often or consistently. For scenario 1, crews also rated that impending conflicts were shown "moderately clearly" ($\overline{x}$ = 3.77, σ = 0.66, n = 9) (Appendix E, Figure E5).

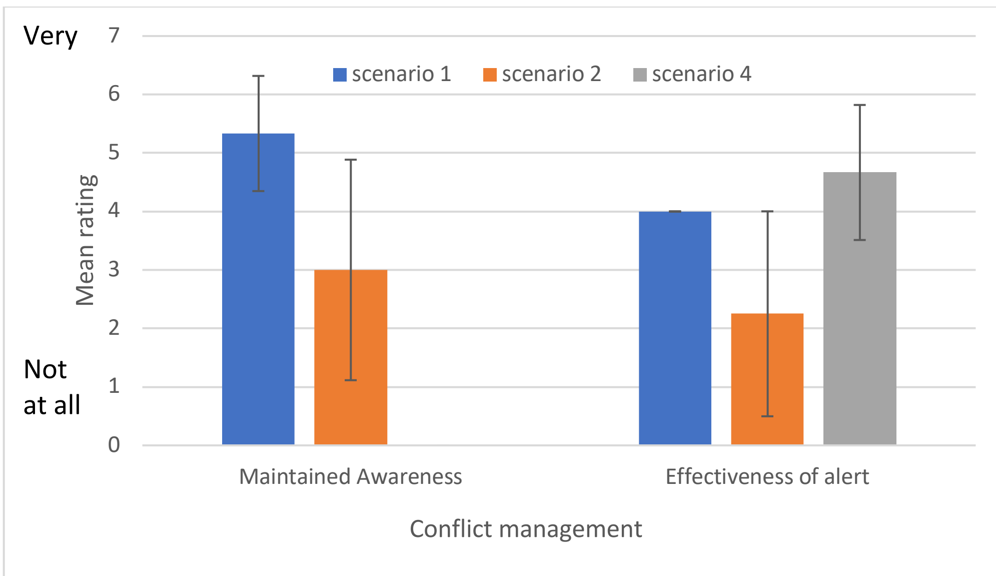

Figure 13. Participant ratings on conflict management: Awareness of conflicts and effectiveness of alerting. N-awareness = 22, n-effectiveness = 15, 1-7 scale extended to show full standard deviations.

3.5.1 Participant and Observer Comments

Crew feedback focused on situation awareness, both in terms of having information about conflicts available and also in terms of that information being quickly and easily understandable. Crews had difficulty building trust in the alerting due to concerns about technical issues. A number of crew and observer comments support this summary.

Crews emphasized that having a visual representation of a conflict was very useful. They argued that it is important to be informed of a conflict, but being able to see the spatial relationship between vehicles adds meaning. Crews listed a number of additional parameters they would like to have added to conflict displays to provide richer information about conflicts. These items included: how soon the conflict was due to happen and more information about non-conformance.

However, one visualization that crews reported they do not need is a conflict display that shows a large airspace with every conflict in that airspace. One or two participants even said they would not need to see conflicts outside of their own volume, if their volume was large. They emphasized that they need to see the conflicts that are close to their vehicle, and that outside that local threshold/ radius, the information is less important.

Crews emphasized the importance of accurate messaging and position reporting so they could be sure when other vehicles were straying into their volumes and when they were not. Although this report does not address technical issues with UTM, within the function of conflict reporting there was a technical issue that affected whether crews were made aware of conflicts. Differences in the ways vehicles reported their altitudes were highlighted by more than one crew. This resulted in both false positive conflict alerts and false negatives where alert notifications were not sent for actual conflicts. While this is an issue on its own for the UTM system and single-vehicle conformance reporting, vehicles that are reporting their altitude using uncalibrated or different base measurements negate the usefulness of conflict detection and alerting. Crews noted that as long as they lack confidence that other vehicles are flying at the altitude presented on the user interface, they cannot rely on UTM-based conflict alerts. Standardization of base measurement and accuracy of position reporting is key for conflict representation.

3.5.2 Requisite Properties Within UTM for Conflict Alerting

Crews emphasized their preference for a visual representation of conflict situations, with displays providing up-to-the-second information. However, they reported a low level of confidence in the alerting currently available due to concerns about technical issues.

- Users would welcome additional information about ownship-other conflicts:
  - users favor a visual representation of conflicts.
  - optionally limit conflict representation to a local area.
  - users need clear messages about the time and location of conflicts.

These properties will support crew situation awareness and decision making, raise user confidence in the UTM system, and improve operator-USS communication.

- Demonstrably accurate (altitude) measurements need to be provided, which will primarily increase user trust in UTM and improve alignment with UTM guidelines by supporting accurate crew situation awareness.

3.6 UTM Function: Alerting with a Focus on Alerting for CNS Failures

In addition to conflicts and being outside of volume parameters, alerts were sent through the USSs for a number of other UTM states, e.g., to warn of UVRs and, for some USS, to warn if a USS-USS negotiation resulted in an operation re-plan, and to warn crews of vehicles that were experiencing simulated CNS issues. All three scenarios had at least one vehicle that simulated CNS issues, but scenario 4 included a large-scale simulation of CNS failure that affected many operations (see SOW, TE-11 to 13, Rios, 2018).

UTM alert messages were shown across a number of displays. One crew had UTM information integrated into the PIC flight-planning interface, enabling the pilot to receive and see UTM messages while operating the vehicle. Observers commented that alert messages were clear and effective on some of the USS interfaces. In general, crews who used their USS and other information to track the location of their aircraft at all times reported their SA was good. However, observers noted that crews used multiple sources of information. For example, when the pilot received UTM messages about a rogue state due to loss of command and control (C2), the pilot cross-checked this information by calling on the radio to get more information. Crew assessments of the timeliness, consistency and helpfulness of UTM information regarding CNS failures was a little more encouraging than their comments (Figure 14). Participants reported that UTM information to support planning responses to CNS failures was "quite consistent" ($\overline{x}$ = 4.9, σ = 2.2, n = 13) and "somewhat" timely ($\overline{x}$ = 4.07, σ = 2.4, n = 13). Although, participants gave more positive responses after scenario 2 than scenario 4. One reason for this could be that crews experienced (genuine non-simulated) CNS interference when they were flying in the downtown location, causing a number of unscripted CNS issues. This is also reflected in respondents' overall assessment that UTM information did not help them during scenario 4, whereas it was "moderately helpful" with resolving their simulated CNS issues in scenario 2.

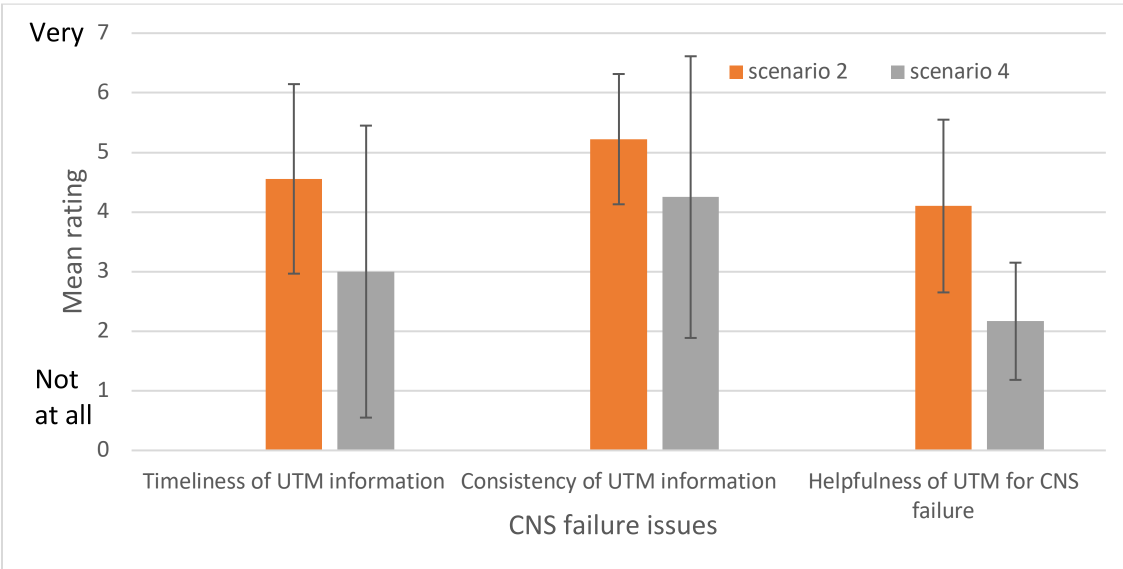

Figure 14. Participant opinions on the quality of UTM information with regards to CNS issues. N-timeliness = 13, n-consistency = 13, n-helpfulness = 16, 1–7 scale extended to show full standard deviations.

3.6.1 Participant and Observer Comments

Crew feedback on alerting in general focused on situation awareness, both the availability of information on factors that could impact their operation, and also in terms of that information being quickly and easily understandable. However, concerns were expressed that the number of alert notifications could become disruptive, and there were indications that crews did not fully trust the UTM alerts they received. A number of crew and observer comments support this summary.

Crews reported that they received alerts but were often unsure about what the alert was signifying. For example, one USS had alerting in their contingency planning function, but the messages were vague and confusing to the crew. In another example, the pilot announced loss of C2 (scripted in scenario) and a UTM message came back through the system that the vehicle was "rogue." The pilot was confused by this, as it was not the message s/he was expecting. Another crew noted that the persistence of alert messages on their USS display was very short; if they were looking at something else, they could easily miss alerts because they disappeared from the display too quickly. These experiences, and others like this, led some crews to comment they would like better alerting from their USS.

Some crews suggested it would be useful to receive alerting about a broader set of conditions than are currently available through UTM. In addition to weather alerts, it would be useful to receive messages about global positioning system (GPS) degradation and cellular networks that are giving intermittent coverage. Other crews suggested that such network outages or issues should be posted on a SDSP application, rather than as a UTM alert, but there was general agreement that good quality CNS information should be accessible to crews. One pilot noted that, although the alerts were useful, the repeated alerting of the same message was distracting. The pilot would like the ability to turn off certain alerts so that crews could manage the amount of information they received from UTM. It was suggested that USSs increase the number of settings, or customization options, allowing more crew choice in the alerts they receive.

3.6.2 Requisite Properties Within UTM for Alerting

Implementation of UTM notices should consider the following qualities:

- Information and alert notices need to convey their message in a clear and concise way.
- Information and alert notices need to clearly state their focus and cause for being sent.
- Information and alert notices need to persist long enough for the operator to see them.
- Alert notices need to have a design that draws attention.

Direction on which notices need to be alerts and which notices are for crew information. These properties will support crew situation awareness and decision making and raise user confidence in the UTM system.

3.7 Core UTM Function: Volumes

One of the core functions of UTM is to check operational volumes that crews have submitted against FIMS rules and other constraints. Operators define and submit 4D volumes through their USS, and then receive a notification of whether the system has accepted their proposal. They activate the volume as they launch. All USSs used in the Nevada test flights showed the own-operation volumes that had been activated on a map, but not all showed information for other operations in a similar way.

AOL Observers counted the uses of information about own-ship operations from UTM and other sources (Figure 15). There were 115 counts across the three scenarios. In scenario 1, information about own-ship operations was received through UTM 77% of the time (n = 33). In scenario 2, information about own-ship operations was received through UTM just a little more often, at 81% of the time (n = 39), and in scenario 4, information about own-ship operations was received through UTM 71% of the time (n = 17).

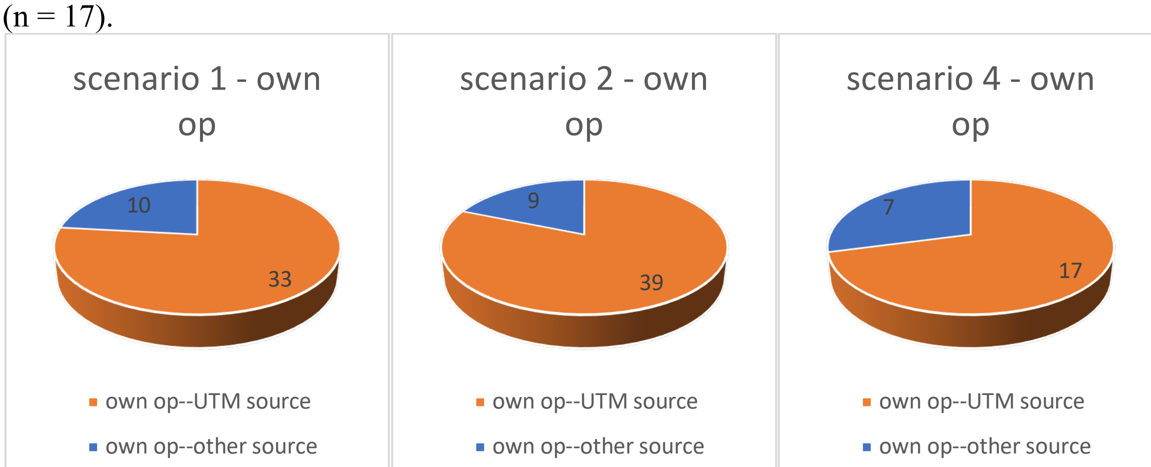

Figure 15. Observer count of items of information shared about ownship status, n = 115.

In scenario 2, crews rated their awareness of their own UTM states as "good" ($\bar{x}$ = 5.25, σ = 2.1, n = 8), but as "somewhat poor" awareness for others' UTM states ($\bar{x}$ = 3.85, σ = 2.5, n = 7). One possible reason for this is that some of the USS clients did not show the operational volumes of any other vehicle than the own-ship. This made scanning for other operations a very difficult task and crews noted that seeing the volumes for other operations was very helpful and useful for their overall SA.

3.7.1 Participant and Observer Comments

In general, crews gave positive reports about the volume submission and management process within their USS, although their actions to confirm the information they received indicates that crews were still building trust with the USS interfaces.

Crew reports on the usefulness of own-ship volume information varied. Some crews reported their USS had good notifications for volume state changes and that volume submission and state changes were clear. Despite this, when crews saw UTM messages about state changes, they often confirmed them via radio. These crosschecking actions indicate a lack of trust in the system but also gave crews a chance to build trust with UTM because the verbal communication confirmed the information presented in the USS interfaces. However, this experience was not universal, some crews found procedures within the USS difficult to execute. For example, one USS only allowed volume cancellation and resubmission while the vehicle was on the ground. This made the useful action of resubmitting while in the air impossible for this crew to execute.

3.8 Core UTM Function: Indicating Rogue Status

Rogue state within UTM is characterized as an operation that is operating outside the conditions or parameters of its accepted volume (Figure 16). There are many reasons why a flight might be in a rogue state, including staying aloft past the end of the volume time window, flying outside the volume, or returning direct to base due to a mechanical issue without broadcasting an emergency notification through UTM. All flights that go outside the parameters of their flight are given a 30 second warning time (non-conformance) during which, if they can return to the conditions of the volume, they can remain flying, if not, the operation becomes irreversibly rogue and the vehicle needs to return to base or land in place.

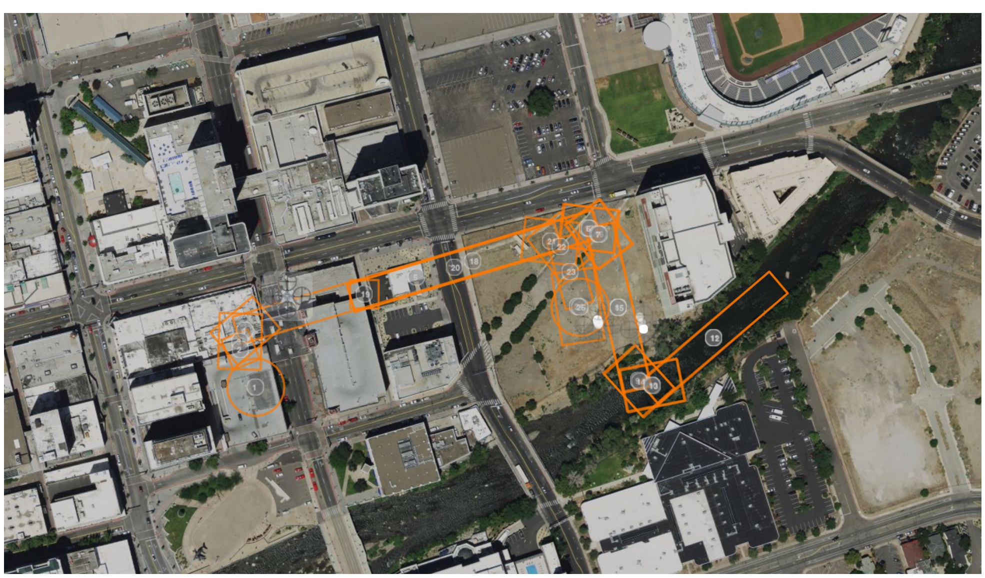

Figure 16. Example of a flight that has rogue status, as denoted by the orange volume.

Participants reported the clarity of indication of their rogue state was "moderate" through UTM ($\bar{x}$ = 4.43, n = 16), although the large deviation (shown in Figure 17) indicates that respondents' ratings varied (σ = 2.4). Participants reported they felt "only a little" uneasy on the occasions their operations went outside volume boundaries (rogue) ($\bar{x}$ = 3.37, σ = 1.8, n = 31, note reverse scale as 1= "not at all uneasy" is a positive rating and 7 "very uneasy" is a negative rating). The mean rating for scenario 4 (urban canyon flying with scripted CNS issues) was higher than the mean rating for scenario 1 (urban canyon flying with no scripted aircraft issues), indicating respondents reported feeling more uneasy about their rogue state during scenario 4 than scenario 1, based on a comparison of means alone (not statistically tested due to a low n). Although, in comparison to these results, observer indicated that during compelling events the crews tended to watch the aircraft rather than their displays. Therefore, crews were not always monitoring the UTM interface, even when it was giving correct status messages.

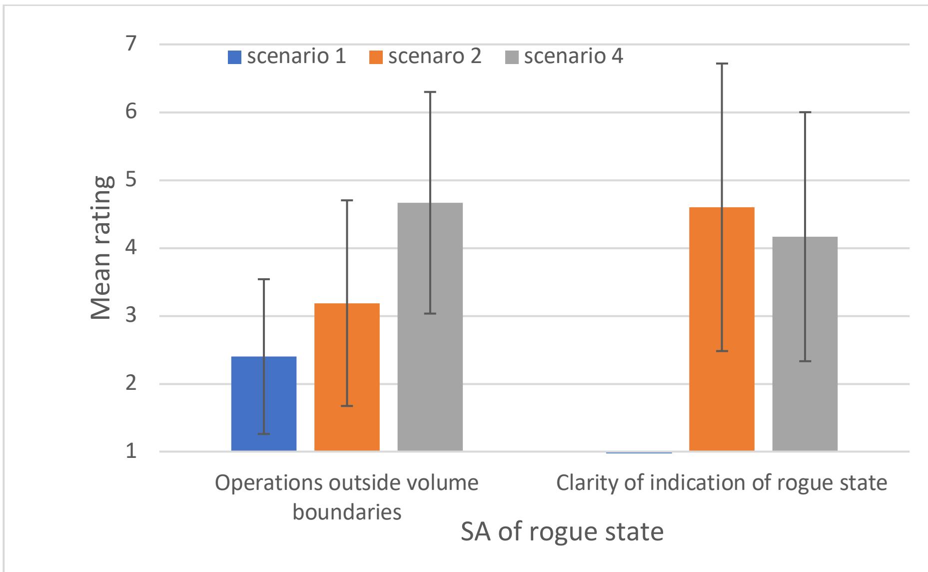

Figure 17. Participant opinions on their uneasiness about nearby rogue vehicles and clarity of this indication, n-operations outside = 27, n-clarity = 16, 1-7 scale.

3.8.1 Participant and Observer Comments

Crews stressed that UTM status (e.g., accepted, active, rogue, etc.) needs to be clearly shown on the USS interfaces and out of conformance status needs to be reliably flagged. Software bugs and glitches, and altitude readings using different bases, led to some operations being marked by UTM as rogue when they may not have been. However, UTM was also observed by researchers to show the correct non-conforming and rogue status and so the above inaccuracies were not always present.

Because crews followed up many of their USS notifications through conversations with other crews, participants reported USS messaging could be inconsistent between USSs. Some operations had the same status (e.g., non-conforming) but only one received the corresponding non-conforming notifications. Due to mismatching USS notifications, crews felt they needed to continue to cross check the information they received with other sources of information, but observers noted that users found this frustrating.

3.8.2 Requisite Properties Within UTM for Core UTM Functions

Crews found UTM volume status information useful. However, they did not fully trust it, and this had a valid foundation. At times, the input information was incorrect, which led to the volume status, at times, being incorrect. To increase user trust:

- Information about own-ship volumes should meet the criteria that are applied to all USS:
  - actions on own-ship volumes should be available throughout the operation's cycle
  - information about own-ship volumes is consistently presented

These properties will support crew situation awareness and decision making, and raise user confidence in the UTM system.

- The way USSs display rogue-state messages needs to be clear, consistent, and concise:
  - criteria determining when a rogue state message is sent should be common across USSs (improve consistency)
  - improve accuracy of rogue-state messages

These properties will support crew situation awareness and compliance with rogue messages, assisting crew reactions and increasing trust in the UTM system.

3.9 Interface Between UTM and its Users

UTM has many interfaces but the primary interfaces of interest in the TCL4-Nevada flight tests were five USS clients designed and built by five different USS developer organizations which were used by the live and simulated flight crews. Of particular interest were the three USS clients used by the five live flight crews. The USS client interface is a crucial bridge in the UTM system between users and automation. The analysis of the users' opinions of the USS client interfaces available in the Nevada flight tests can be found in a separate report by Arbab (2019).

3.10 Interaction with UTM

The core and critical functions of the UTM system work in two ways: 1) by exchanging information somewhat autonomously between the elements of the UTM network, e.g., USS-to-USS; and 2) by providing information to users (in this report, to flight crews) who need to be aware of and act on this information. This crew-USS interaction (or human-system interaction–HSI)) affects users' perceptions of the system and the way they approach being part of and interacting with that system. Four attributes of user affect were probed in surveys and debriefs: SA, trust, knowledge gained, and communications.

Although the UTM system is designed to be autonomous in many respects, users were required to interact with the system via their USS, to submit volumes and manage operations, and then to monitor their interface for feedback and updates. While there are many properties of interface design that have been researched (see work by Nielsen & Molich (1990) and Norman (2013) for example) essentially users should be provided the information they need to accomplish their work by their tools. To complete their tasks safely and efficiently, users need USS interfaces to support: 1) their understanding of what is occurring in the UTM system and in the physical airspace, and 2) their ability to interact with thte user interface to change the course of those events if needed. Therefore, users are looking for the UTM system to provide them with appropriate information that they can trust, supporting them to build good SA of the environment, and that they can effectively communicate with the system to change its actions. Users were queried about whether the UTM system provided them with these four attributes that they needed.

3.10.1 Interaction with UTM: Communication/Messaging

The starting point for successful interaction with UTM is for the system to communicate well with the user. Observers noted that many of the messages received reflected good effective communication between UTM/USS and the user. For instance, flight crews appeared to have a solid understanding of the next steps and actions to take once they received messages from the system. One example of UTM messaging was the "all clear" message that crews received after a UVR was taken down and operations could resume in that area. Fifty-eight percent of respondents saw the "UVR-cleared" message during either scenario 1 or scenario 2 during the Nevada flight tests (n = 14) (Figure 18). A third were informed by word of mouth, while a very small number were unaware when the UVR was cleared.

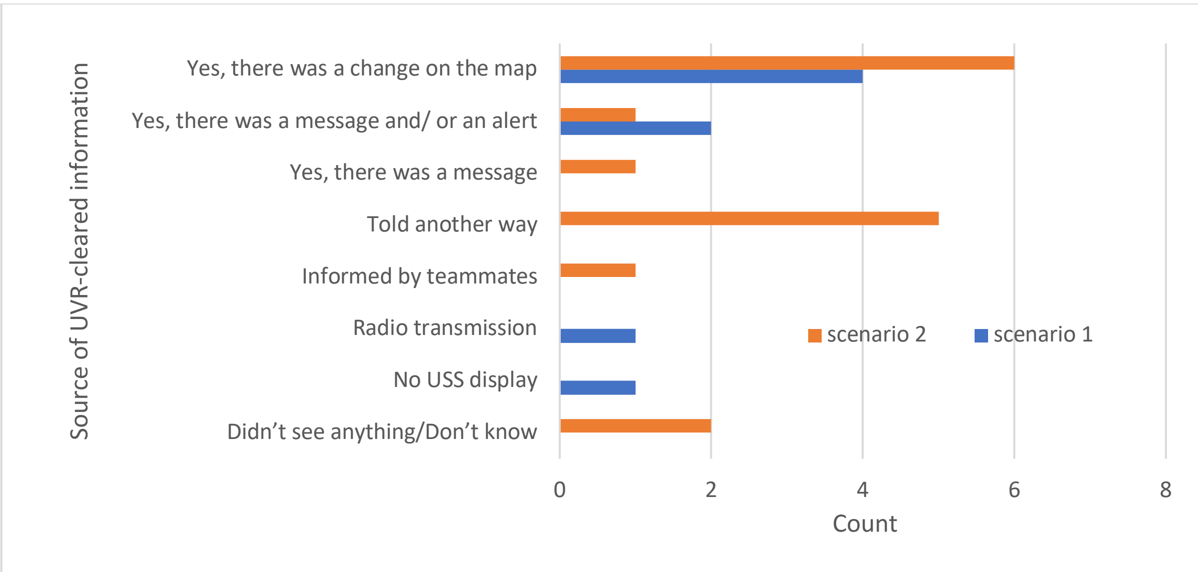

Figure 18. List of sources for UVR-cleared messages sent when a UVR is taken down, n = 24.

There were numerous reports from observers that UTM messages and communications were timely and effective. Observers described crews using the messages they received to confirm their actions and to make decisions. They also noted that crews understood the messages they received and knew how these mapped on to actions they needed to take. Observers estimated that USS message displays were clear and effective.

Communication issues resulted from the user feeling that a message was either not delivered effectively or that messages lacked necessary information. In one instance, a user did not know that they were receiving an alert until someone else pointed it out. Another alerting issue pertains to the actual timing of the system sending messages. In some cases, the user received the message over the radio before receiving it through the USS. Ideally, alerting messages would be received in a timely manner to allow for users to react. There were also instances of messages that lacked necessary information and therefore, were ineffective. For instance, the implementation of a UVR must trigger a USS to send a clear message to all operations in the area as to whether or not they are permitted within the UVR. Overall, users need ample information in order to be fully knowledgeable of a situation before re-planning. Missing information in a message may result in a delay that could prevent a successful operation or re-plan.

As indicated above, some crews were less trusting of UTM, relying on visual feedback and radio communications rather than USS messages. Observers noted that those crews who did not have other operations displayed on their USS used as many other means as they could to confirm their locations, including Slack (Slack Technologies, 2019) and voice comms. These crews with limited "windows" into UTM were assessed by observers as trusting the UTM system less than those who had more complete displays. For those crews whose USS was only able to show them their own operations, the RelmaTech app provided a situation awareness display that showed nearby operations.

Key USS communications are those that provide information about basic status and airspace changes. As noted above, users did not feel that the status messages were clear enough. The presentation of status messages should be salient, the meaning of the message should be unmistakable, and the rules that govern status should be standardized and consistent, and provided in guidelines.

3.10.2 Interaction with UTM: Information Efficiency and Effectiveness

In order to be usable information for the UTM user, data provided by the UTM system needs to be useful, accurate, reliable, and conveyed in a timely manner. Crews discussed the degree to which the USSs provided information to their team and how this could be improved.

In terms of information that crews would like to receive, crews noted that, when they are flying live operations, they would like as much information about their own flight, other flights and UTM activities as possible. They stressed that knowing where other aircraft are is a critical piece of information, especially if UTM predicts that other operations are going to be close to their own or, in particular, intersecting at some point, as this information was not available from some USSs. Crews discussed that sharing information benefits everyone. If one crew broadcasts their situation to all those affected that they have changed their plans, this would allow other crews to amend their plans so that they are minimally inconvenienced by the changes.

There was also a debate about the number of displays and devices a crew had to monitor. Some pilots commented that having to assimilate and process information from three or more sources was workload intensive and made the information they received more difficult to act upon. They suggested that combining all the information into one location would streamline decision making. They advocated that the GCSO should receive all USS messages and that the messages should have a link back to the information that triggered them.

At the same time, other crews noted that some non-critical but very useful information would be well-placed in a different location, such as in an SDSP. Weather information is one example of this. Crews noted there is a lack of weather information between the ground and 400 feet, and that an application or site that could collect and present weather information at these altitudes would be extremely useful.

There were also some items of information that users found difficult to interpret or use. For example, crews reported confusion when activities in UTM did not go as planned. When a crew's submission was rejected, the crew was not provided an explanation for the rejection. They commented that it took too much work to try to find the reason. Observers noted that flight crews needed assistance from the USSs developer to understand their flight status and other messages. This suggests that the USS interface needs to include more explanatory information so that crews understand why UTM events are happening.

However, other participants noted the possibility that there could be information overload if a USS presents all messages and interactions within UTM. Crews discussed that although they would like a lot of information, they would not want it all to be visible at the same time. In another discussion, crews stated that they had a variety of tasks and could not watch the USS all the time. Observers noted that this was the case and that, on a couple of occasions, UTM messages arrived and crews were not aware of them as they were doing other things. In debriefs, crews discussed a number of ways the USS interface could be enhanced to make more information accessible (see Arbab, 2019). During discussions, crews agreed that information about other close-by operations should be considered critical, high-priority information.

3.10.3 Interaction with UTM: Procedures

To use information effectively, users need strategies, which can be defined as procedures if the action sequences have to be made often. Because the USS clients had many new elements, there were few formally-defined procedures for operating with UTM during the flight tests in Nevada. Crews drew often on pilot procedures from manned aviation, e.g., one GCSO counted down the UAS phase change aloud, so the whole crew knew about it. Crews found some of these newly-formed procedures to be effective when they tried them, while others were ineffective. The focus of the current paper is on UTM information exchange and does not explore procedure development for UTM but consensus should be reached among users about how best to implement often used task sequences and which should be standardized as formal procedures.

3.10.4 Interaction with UTM: Situation Awareness

Humans use the information they receive to build situation awareness (SA) of events and their circumstances. In general, people find it easier to build SA if the information they are using is clear and formatted in a way that means they do not have to work to interpret or manipulate the information before they can use it.

Observers recorded instances of crews using their USS to establish situation awareness and instances where they did not. Observers reported that those crews who *used* their USS, did so regularly, to see UTM information and check to confirm their UTM state. For one USS that showed other operations using the same USS company, crews also checked positions of other vehicles. The observer estimated that crews obtained useful situation awareness from these clients. For instance, in one run, observers noted that two crews saw through their USS displays that their vehicles were coming closer within their volumes than they (the crews) were comfortable with. Using their USS displays, crews resolved the issue by discussing their intentions with each other and worked out a series of steps where one vehicle loitered while the second maneuvered around the first.

Some crew-members actively supported building their awareness by following up on information they saw on their USS via radio or person-to-person. Observers noted instances of the PIC talking to their USS operator to make sure they were fully aware of the situation. The added advantage of these discussions was that they ensured everyone impacted by the information was aware of it. In addition to basic information, crews discussed the importance to SA of having context to support UTM messages. For example, in cases of conflict, the pilot is able to make better decisions if they can know from which direction the conflict is going to occur and what distances are involved.

Observers noted that there were a couple of missing items of information that hampered crew situation awareness. Missing information was particularly detrimental during periods crews could only see their own-ship operations and could not see other nearby operations.

3.10.5 Interaction with UTM: Promoting Trust and Confidence in the System

The process of being able to develop situation awareness from information provided and that information being both useful and accurate, leads users to develop trust in a new system (Miller & Parasuraman, 2007).

Observers noted that some crews trusted the UTM states shown by their USS, and also trusted that they were non-conforming or rogue if their USS reported this state. However, some crews were less trusting of UTM, relying on visual feedback and radio communications rather than USS messages. Observers noted that those crews who did not have other operations displayed on their USS used as many other means as they could to confirm the locations of other vehicles, including Slack, and voice communications. These crews with limited “windows” into UTM operations were assessed by observers as trusting the UTM system less than those who had more complete displays. For those crews whose USSs were only able to show them their own operations, the RelmaTech application provided a situation awareness display that showed nearby operations.

One way in which crews could build trust in a prototype system is to cross-reference information to confirm by matching the new source of information to a trusted source. Crews reported they crosschecked UTM information regularly ($\overline{x}$ = 3.57, σ = 1.8, n = 7) suggesting that they were actively trying to build trust. They used radio communications and Slack to double check the information they received via USS.

Observers noted that basic UTM operations were trusted without checking but newer functions and safety events were looked into more carefully and information was crosschecked. Other observers noted that they did not see full trust in the UTM system, in particular because the USS displays were not showing all the information that crews wanted, especially the locations of other operations. The presence of other aircraft had to be monitored through radio communication or visual observers.

An overall issue that affected all crews was the recurrent issues with altitude reporting. This, while not a UTM issue, affected users’ trust in the UTM system. They could not be certain that the altitudes reported by UTM were accurate as vehicles were not all reporting altitudes using the same base measurement. Because of this, they did not trust UTM and frequently used the radio to talk to other flight crews about their altitudes.

3.10.5.1 Promoting Good User Interaction with UTM

To support user situation awareness and user trust, basic properties that make information usable apply as much to the information exchanged by UTM as to any other automated system that interfaces with a user. Users are able to establish better situation awareness if:

- Messages are clear.
- There are guidelines or notes available to explain information in messages.
- More important or time sensitive messages need to alert the user to ensure they are seen in time.
- Alerts should be informative and obvious to the user to prompt an appropriate and quick response.
- Contextual information is provided.
- Information is consistent across displays.

4. Summary and Conclusions

UTM Technology Capability Level-4 (TCL4) flight tests were completed in Reno, Nevada during June of 2019. Pilot participants flew 318 operations, of which 71 were live flights, to demonstrate sequences of events within three sUAS scenarios. The qualitative data discussed above were collected by on-site AOL researchers, and consisted of end-of-day debriefs, end-of-day surveys, observer notes, and observer event counts.

From our research question, observing the Nevada TCL4 flight test demonstrated that crews were supported by UTM functions when flying in urban environments, however, they were not fully supported as in some cases, the user interfaces did not provide clear information to the users. User feedback suggests that they would like to act appropriately when negotiating with other USSs, when responding to UVRs or conflicts, and when interacting with/as a priority operation, but they lacked clear guidance about the bounds of appropriate actions for each situation. Crews would like to know the cause of events, as the behavior of the system would then become more predictable, and they, as users, would also be better equipped to act as expected. For example, when crews understood the system logic and features available to them as a priority operation with simulated failures, they thought it useful to be able to elevate their priority, construct a new volume to accommodate a direct return to base (RTB), and maintain their conforming state. An opposing example is when one crew initiated a RTB without a new volume, then encountered rogue messages that they did not expect, did not know the cause of, nor know what the best response would be. In sum, UTM has the potential to foster common situational awareness of the airspace and operations within it to support sUAS operations (MOP, Rios 2019, sheet 2, MOE 4) but requires improvement to meet that. More insight or visibility into the processes, and how all elements of the system behave, could level the playing field of expectations and increase overall user situation awareness and system efficiency of the system beyond current day.

One possible method to aid users' awareness is through UTM messages and notifications, keeping a balance between too much and too little information. The information should be rich enough to provide context, be user-centric and relevant to the own-operation, arrive at the right time and with the right frequency. Some information elements specifically mentioned were to include the reason for rejected negotiations, permissions for being within a UVR, explanation for state changes and within conflict messages, and give the timing and nature of those conflicts. Crews would like these messages to be clear and concise, and if the message is high priority, be salient enough to draw their attention, and persistent enough to be seen if their attention is not actively on that display. They discussed having visual representations displayed for volumes, UVRs, and detected conflicts, but stated that, as with text notifications, these should also be relevant to their own operation. Observers noted that crews were sometimes saturated with too much information, and crews stated that it would help to limit the information on their display to what impacts them, so they don't have to read and filter while their vehicle is on a mission. Some crew members suggested allowing users to customize options for notifications, messages, and alerts.

Beyond effectively relaying relevant information to the crews and supporting their understanding of what action is appropriate once that information is received, crews wondered if automation could offer solutions to issues. For instance, if the known proper response to a UVR being erected over non-permitted active operations is for those operations to RTB, then there could possibly be a prompt delivered to the user that, once clicked, draws a new deconflicted volume. Stated concerns about the ability to "game" the system to achieve a desired outcome, the possibility for many cascading negotiations or unforeseen future conflicts from negotiations could also possibly be mitigated through additional automation, user customization, and/or more education for the user on appropriate actions to take in different situations.

For human-system interaction to be successful, the user needs to have an understanding of the way a system works in order to use this knowledge to develop current and future situation awareness—in Endsley's terms, comprehend the meaning of the situation and project into the future, (Endsley, 1995). For the UTM system, crew knowledge is centered around two things: a general understanding of the concept and understanding the guidelines that govern the way UTM functions work in terms of HSI. Feedback from crews in the Nevada flight test suggested that the guidelines available for the UTM functions exercised in the flight test were not detailed enough for them to be able to successfully use and follow in the test site's operational setting. Overall, crews requested more guidelines about UTM conditions, UTM status, and UTM restrictions. The conditions crews were concerned about were those associated with USS-to-USS negotiation, their status concerns were linked to when they or another local user were assigned priority, and their restriction concerns were for when UVR were in place. Discussion suggested more information in the form of guidelines about the implications of selecting or working under a set of conditions would assist users, for example, what the implications are if you agree your operation will negotiate. Also, more guidelines about orders of priority status and the implications of being a higher or lower priority than a nearby user, and more information about the options available when a UVR activates.

Data collected from flight crews aligned with five attributes (Figure 3) and indicated that UTM did provide information that contributed to users' ability to operate safely and effectively within UTM, but that information was not complete.

- Crews reported they had good situation awareness of their own-ship. As noted above, they did not always fully understand the UTM information they had access to, and had questions about their operation and the environment. Some of the items of information items requested were not sufficiently usable, salient or intuitive.
- Crews did have a high level of safety awareness and were very tuned to risk perception and management. While the risks of urban canyon TCL4 flying were clear to crews, they were less sure of, and discussed in detail, future risk situations where flights have less oversight and preparation, e.g., a real safety UVR where crews have to make immediate decisions about whether to return to launch and how to exit the space. They emphasized the need for more clarity in guidelines for these situations and information to be made available that is easily usable for risk management.
- UTM system-to-user communications were possibly better than users were aware of. Few messages were alerted, either visually or aurally (although the four USS varied greatly in their interfaces), with the result that sometimes crews did not see messages. Most communications (messages, notifications, alerts) received by crews were understandable but, as described above, there were occasions when the notification crews received was not the one they expected.
- Users were not required to base their decisions and actions on UTM information alone in the TCL4 test, there were multiple sources available for them to cross-check information. Observers noted a good amount of crosschecking occurring across the test suggesting that confidence and trust in UTM was being established.

- Crews felt they responded efficiently and effectively to UTM information that required them to take action. However, often they chose to act outside of UTM to solve the problem using manual skills, but it is not clear whether users did this because they could not use UTM or through habit.

The TCL4 flight tests successfully demonstrated flying UAS through an urban canyon and other highly-populated areas. Qualitative data collected showed the usefulness of the UTM system and the need for information exchange for users of the system. Survey and debrief responses underlined crews' desire to be informed about operations other than their own and their need for clear procedural guidelines and clear displays of information. The findings presented above complement data previously collected for TCL3 (Spring, 2018), TCL2 National Campaign (Spring, 2017), and TCL2 (Reno, 2016). The increased functionality of UTM markedly increased its usefulness over previous flight tests, but also identified that some of these functions would benefit from more consideration.

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Appendix A

Table A1. Crew Member Roles and Responsibilities

Crew Member Role	*Crew Mmber Responsibilities*
Pilot-in-command (PIC)	Served as the main pilot for the vehicle
GCS operator (GCSO)	Worked the vehicle's flight planning and flight execution software
USS operator (USS Op)	Monitored and interacted with USS displays (& NASA)
Hardware and software flight engineers	Supported specific technical aspects of the vehicle
Visual observers (VO)	Safety monitors who provided visual contact with the vehicles at all times
Additional Roles	*Responsibilities*
USS manager	Ensured the USS software was running and undertook troubleshooting when needed
Landing zone safety pilots	Served as monitors at beyond visual line of sight landing points
Flight rest manager	Coordinated the crews and flights to conduct the test scenarios properly
NASA researchers and observers	Collected observational and survey data, observers were available to support media day and answer flight team questions

Appendix B

UTM Achitecture

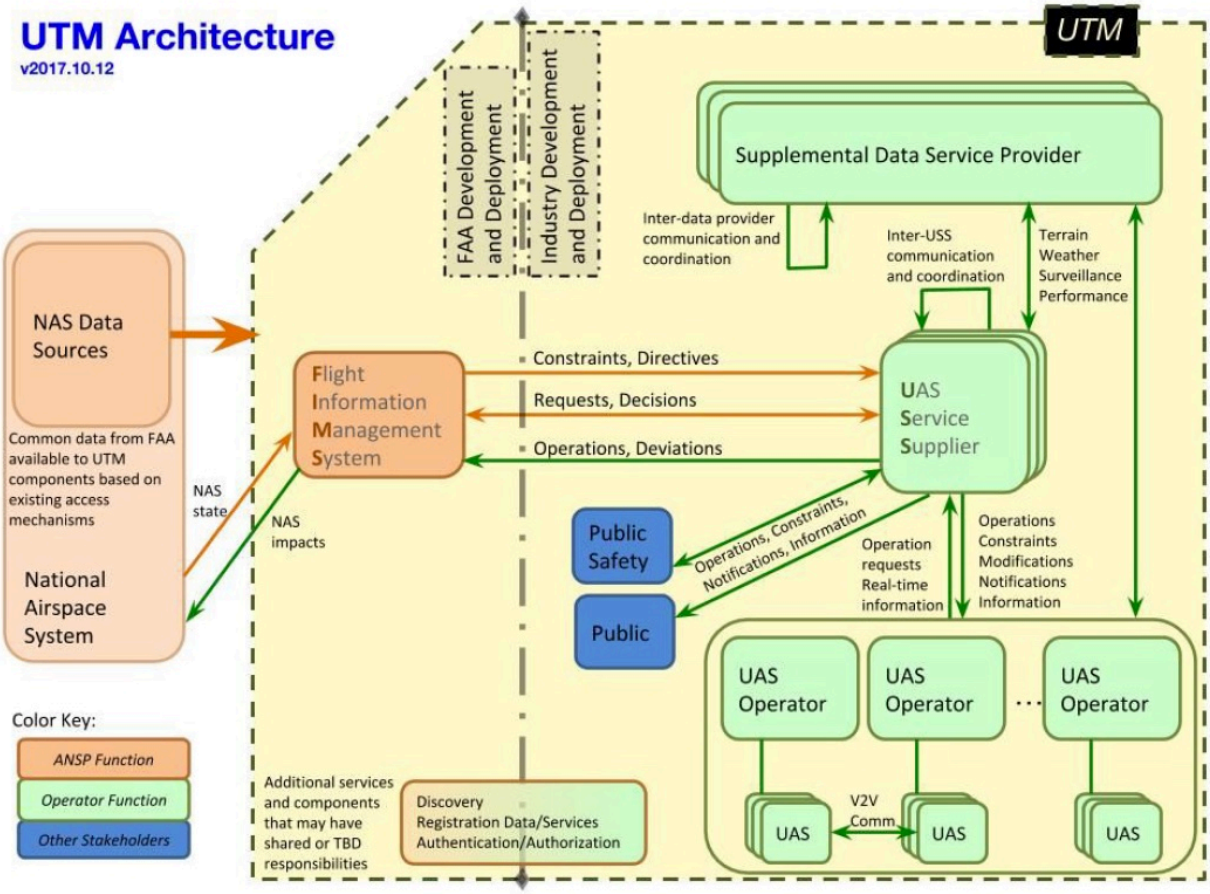

Figure B1. UTM architecture.

Appendix C

Table C1. Participant and Observer Statement Coding Scheme based on Research Question Topics

Research Category	*Sub-category*	*Research Category*	*Sub-category*
Communication/ Messaging	Effectiveness of data (message)	Safety and Risk	Safe separation
	Quality of alerting information		Confounds
Usability of information - Information efficiency & effectiveness	Reliability and/or accuracy of information		Priority access & priority operations
	Appropriateness of decision made (maneuver)	Procedures	Planning process and considerations
	Workload		Procedures for flight or event
	Usefulness of information		Description of operator role
	Usability tradeoffs		Public and hobbyists
	Intuitiveness or interpret-ability of information	Trust	Confidence in decision made (maneuver)
	Easy to understand		Trust in information presented
	Information timeliness		Reliance on info presented
Situation Awareness	Transparency of tool		Operator buy-in
	Situation Awareness	Automation	Definition of terms
	Information required or desired		Design of system or hardware
	Saliency of information		Functions
	Information timeliness		Concept issues

Appendix D

General Description of Data

Observers counted the uses of four types of UTM information from both UTM and other sources. There were 190 counts across the three scenarios—61 during scenario 1; 94 during scenario 2; and 35 during scenario 4. The majority of the observations/counts were for information about the crews' operation (60%). Of the remaining 40%, half of the observations were about UVRs, a quarter about negotiation and a quarter about priority operations.

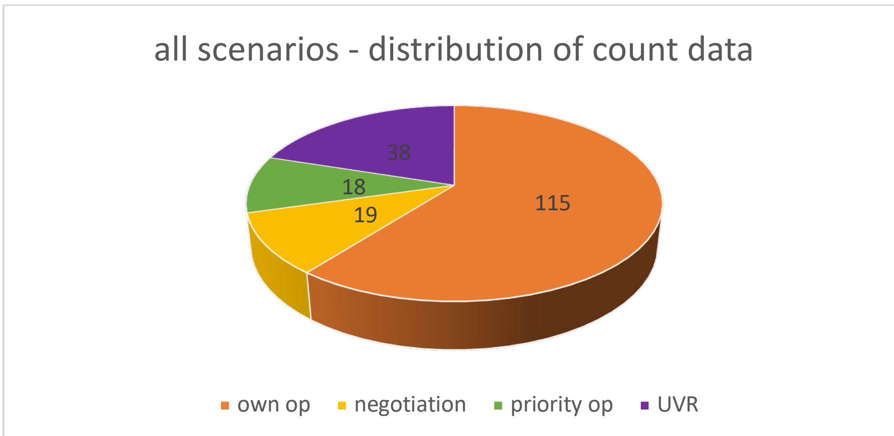

Figure D1. Observer counts of uses of UTM information by flight crews, n = 190.

Appendix E

Participant Survey Responses on Negotiations, Priority Status and Conflict Alerting

Negotiations
Participants reported only wanting to be "regularly involved" ($\bar{x}$ = 3.76, σ = 1.6, n = 34) with the USS-USS negotiation process.

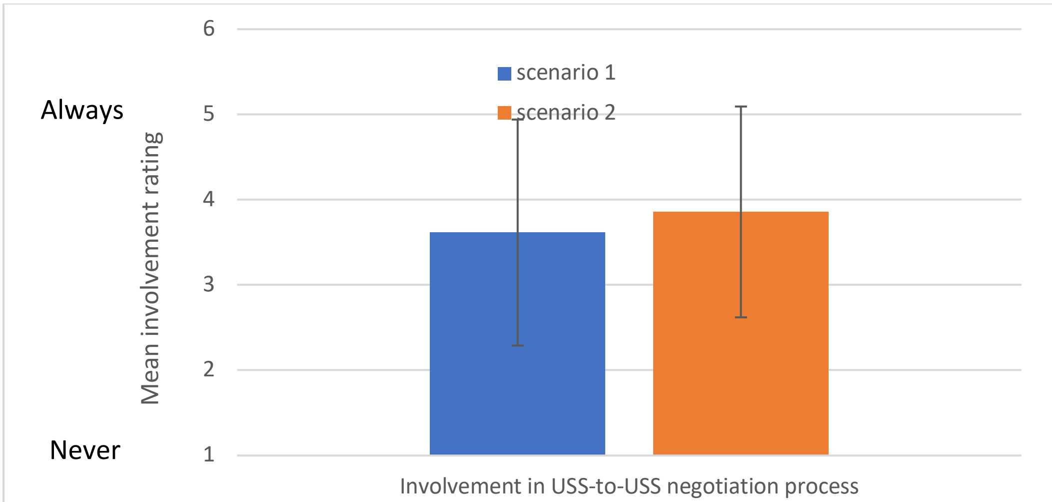

Figure E1. Participants' desired level of involvement with the UTM negotiation process, N = 34, 1-5 scale extended to show full standard deviations.

Priority
Participants reported that information about another vehicle's compromise and declaration of emergency priority arrived at close to the right time but verging on a little late ($\bar{x}$-self = 4.33, n = 9; $\bar{x}$-other = 5.16, n = 6).

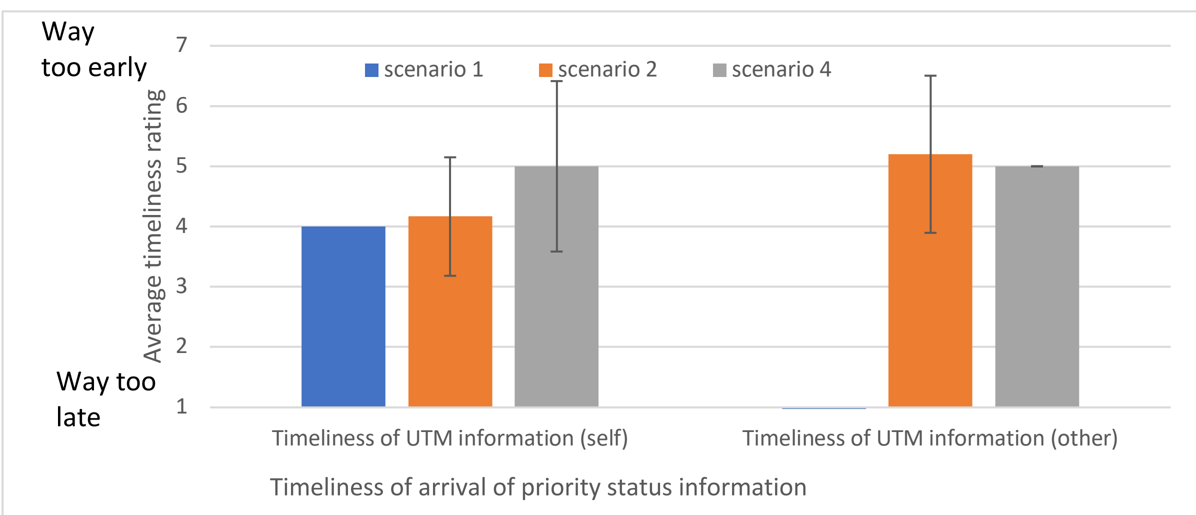

Figure E2. Participant reported timeliness of arrival of priority flight information during UVR activation, N-self = 9, n-other = 6, note the low n; 1-7 scale with 4 = "on time" as the most positive point on the scale.

Priority Status

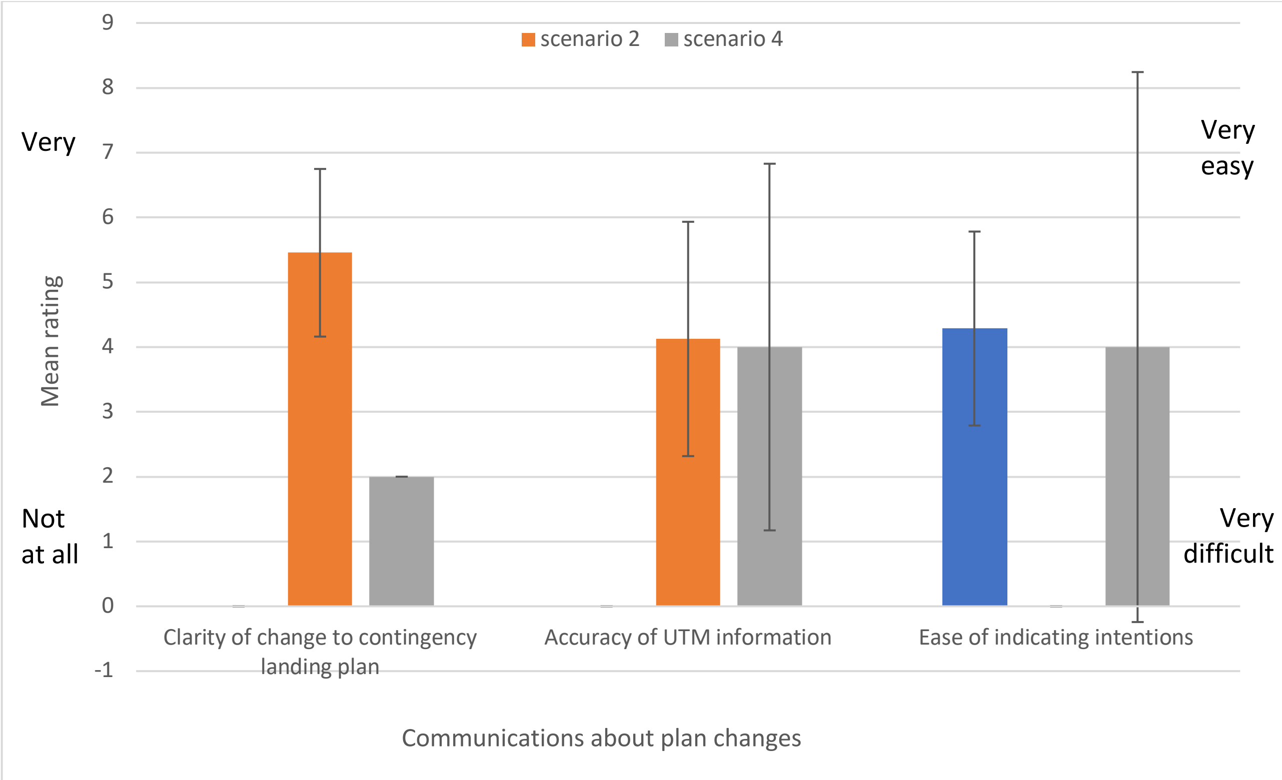

Figure E3. Participant reported properties of messages about plan changes,N-clarity = 13, n-accuracy = 10, n-indicating intentions = 9, 1-7 scale with scale extended to show full standard deviations.

Conflict Alerting

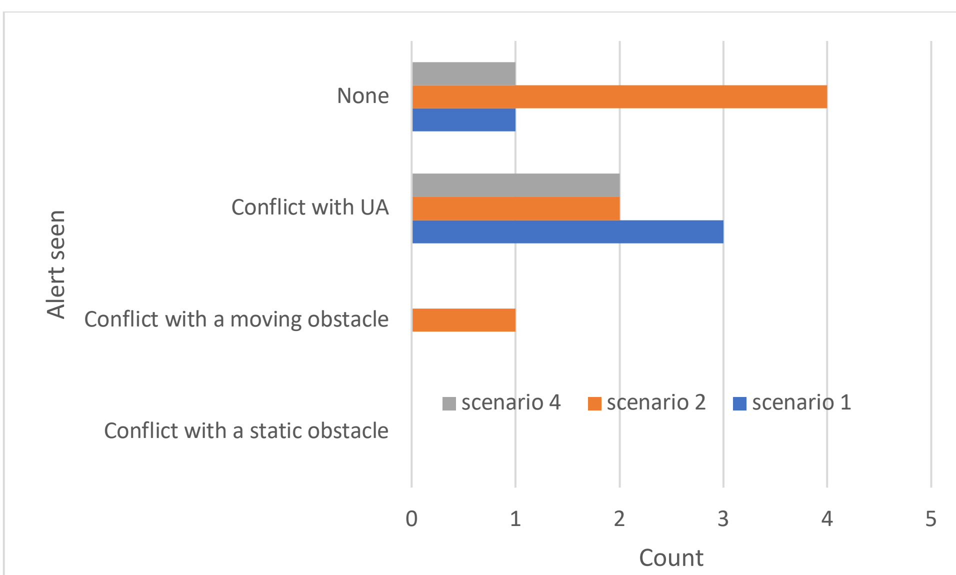

Figure E4. Alert messages participants recall seeing on UTM, n =14.

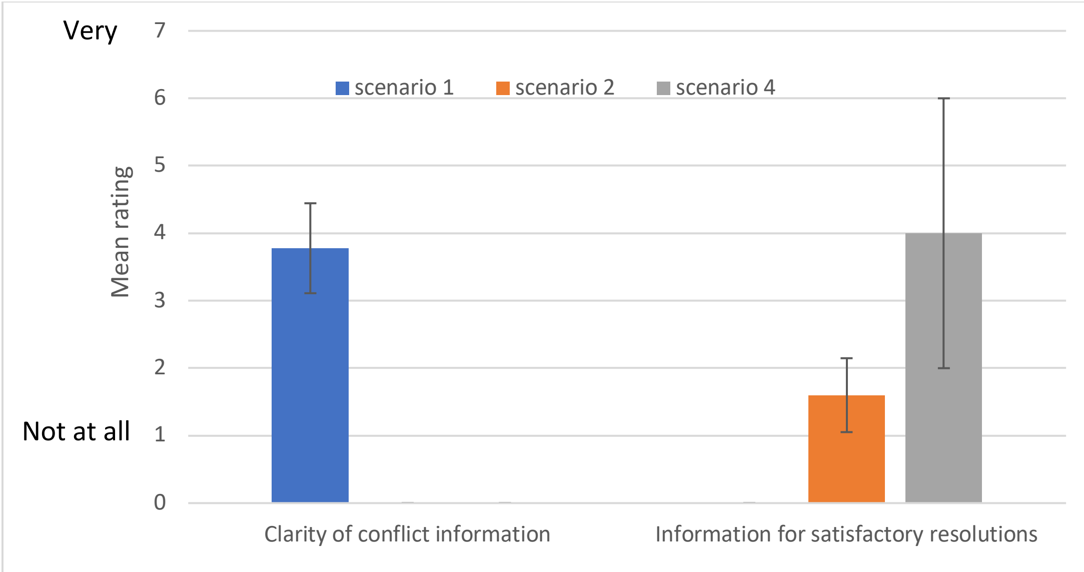

Figure E5. Participant reported properties of conflict information, n-clarity = 9, n-resolutions = 8, 1-7 scale with scale extended to show full standard deviations.

Respondents varied in their opinions of how helpful the UTM system was in planning resolutions to these conflicts, those who had to solve conflicts in scenario 4 reported that their USS client had "some" of the information they needed to plan resolutions ($\bar{x}$ = 4, σ = 2, n = 3), and those solving conflicts in scenario 2 thought the USS client had "no" information to help them ($\bar{x}$ = 1.6, σ = 0.54, n = 5).

Appendix F

Breakout of Negotiation and of UVR Operations

Table F1. Breakout of Negotiation Operations

Location # of negotiations	Nevada 862					
Scenario # of negotiations	Scenario 1 119		Scenario 2 657		Scenario 4 86	
Type # of negotiations	Replan 27	Intersection 92	Replan 2	Intersection 655	Replan 4	Intersection 82

Table F2. Breakout of UVR Operations

Location # of UVRs	Nevada 24			
Type # of UVRs	Dynamic restriction 24		Static advisory 0	
Scenario # of UVRs	Scenario 1 4	Scenario 2 20	Scenario 1 0	Scenario 2 0