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Initial Evaluation of the Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies (IMPACT)

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Interim Report

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14. ABSTRACT (Maximum 200 words)
This report covers the first year of research and development for the Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies (IMPACT) program. The goal of IMPACT is to integrate autonomous technologies like cooperative control algorithms, intelligent agents, and autonomics frameworks with human-autonomy interfaces to support effective supervisory control of multiple heterogeneous unmanned vehicles (UxVs) in dynamic operating environments. With IMPACT, the human-autonomy team controls multiple UxVs by utilizing high level commands called plays. To evaluate the year one IMPACT system, seven participants were asked to use IMPACT to manage six UxVs in the context of a base defense mission. Participants rated both the overall IMPACT system and system subcomponents (play calling, autonomy, feedback, and test bed) positively. Objective data was also collected on the modality (mouse/keyboard, touchscreen, speech recognition) participants used to call plays. Participants not only used the mouse/keyboard more frequently, but also were faster and more accurate with the mouse/keyboard as compared to the touchscreen and speech recognition. Participant feedback has directly led to planned enhancements for the Spiral 2 IMPACT system.

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1. SUMMARY

Autonomous technologies that support unmanned vehicle (UxV) operations are typically developed and researched in isolation. The goal of the Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies (IMPACT) research effort is to integrate cooperative control algorithms (CCAs) that optimize route planning, intelligent agents (IAs) that recommend optimal courses of action, and an autonomics framework that can monitor plans against situations to help an operator manage multiple heterogeneous UxVs in dynamic operating environments. IMPACT is a three year effort that seeks to combine these autonomous technologies with innovative human-autonomy interface (HAI) concepts that allow operators to effectively supervise multiple UxVs via high level commands called plays. For example, when an IMPACT operator calls a play to obtain air surveillance on a building, the IA recommends a UxV to use (based on estimated time enroute, fuel use, environmental conditions, etc.), the CCA provides the shortest route to get to the building (taking into account no-fly zones), and the autonomics framework monitors the play's ongoing status (will the UxV arrive at the building on time).

This report describes an evaluation of IMPACT's Spiral 1 system. Three UxV operators and four security force personnel were trained on IMPACT's autonomous technologies and asked to manage six UxVs (three unmanned air vehicles, two unmanned ground vehicles, and one unmanned surface vehicle) in support of a simulated base defense mission. Feedback was sought on the HAI's candidate display formats, symbology, and input modalities (mouse, touchscreen, and speech recognition) as well as the CCA, IA, and autonomics framework. Subjective data were recorded via questionnaires and analyzed.

Participant feedback was uniformly positive in regards to IMPACT's potential value to aid future UxV operations, to reduce operator workload, and to increase operator situation awareness. Participants also rated the autonomous technologies and HAI favorably. Additional data were collected on the modality participants used to call plays. Participants made play calls using the mouse more frequently than the touchscreen or speech commands. Play calling with the mouse was also faster and less error prone than calling plays with either the touchscreen or speech commands.

These findings will be used to help refine and demonstrate effective human-automation interface and interaction technology for future UxV control employment concepts. Specifically for IMPACT, these findings have led to planned improvements for IMPACT's Spiral 2 system, including map-based play calling, map decluttering, and graphical "widgets" to modify play details like loiter sizes. Participant feedback also led to additional research studies focused on how to best organize play calling symbology as well as how to best represent multiple IA generated plans to the operator. IMPACT's Spiral 2 evaluation objectively examines IMPACT's effect on operator performance as compared to a baseline system.

2. INTRODUCTION & BACKGROUND

Future manned and heterogeneous unmanned forces must be able to work increasingly as agile synchronous teams to complete missions in complex, ambiguous, and dynamically changing environments. Advanced and highly reliable autonomous behavior and multi-unmanned vehicle (UxV) cooperative control planning algorithms (CCA) will be required that are far beyond the capability of currently fielded systems. Therefore, rather than a rapid switch from current operations to fully functional autonomous cooperative teams, the likely transition path will involve incrementally fielding component autonomous behaviors as they are developed, with overall autonomous capability increasing over time. Thus a key challenge is, with the addition of incremental and imperfect autonomous behaviors, how best to ensure flexible, robust mission effectiveness across a wide range of situations and with the many ambiguities associated with the "fog of war," of operational environments.

Mission effectiveness will rely on increased agility: the rapid identification and management of uncertainties that can disrupt or degrade an autonomous team's ability to safely complete complex missions. Agility is especially critical to robust team decision making in highly challenging and rapidly evolving situations. One promising method for increasing agility is to establish an intuitive and effective dialog between the human team member and emerging autonomy. With this method, strengths of each can be maximally utilized to resolve any ambiguities and achieve decision superiority, with autonomy being increasingly unleashed as it learns how to detect and respond to increasingly ambiguous situations.

Many researchers are exploring critical autonomy components (e.g., CCA, Intelligent Agents (IA) and human autonomy interfaces (HAI)) in isolation. This research, funded by The Assistant Secretary of Defense for Research and Engineering (ASD R&E) under the Autonomy Research Pilot Initiative (ARPI), is unique in that it applies these approaches synergistically to develop an Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies (IMPACT) system that combines flexible, goal-oriented "play" calling and human-autonomy interaction with CCAs that provide near-optimal path planning solutions, IAs that can recommend task assignments, and an autonomics framework that can monitor the status of ongoing tasks. The IMPACT ARPI is a three year tri-service (Air Force, Army, and Navy research laboratories) effort in researching autonomy with a specific focus on *agility* for achieving decision superiority with a human-autonomy team. This report focuses on the components developed and evaluated in Spiral 1 of this effort: CCA, IA, the Rainbow Autonomics Framework, and HAI.

Cooperative Control Algorithms (CCA)

Recent CCA efforts (Argyle, Casbeer, & Beard, 2011; Chandler, Pachter, & Rasmussen, 2001; Frazzoli & Bullo, 2004; Richards, Bellingham, Tillerson, & How, 2002; Castañon & Ahner, 2008; Karaman, Rasmussen, Kingston, & Frazzoli, 2009; Humphrey, Cohen, & Rasmussen, 2010; Shima & Schumacher, 2009; Krishnamoorthy, Park, Darbha, Pachter, & Chandler, 2012) have focused on developing algorithms for multi-UxV task assignment and scheduling that produce optimal or near-optimal solutions, e.g., to minimize total mission time or total distance travelled. Typically, such research focuses on formulating a joint optimization that assigns agents to requested tasks (Shima & Rasmussen, 2009); however, game theoretic (Arslan, Marden, & Shamma, 2007), rule-based (Cortes, Martinez, Karatas, & Bullo, 2004; Kingston, Beard, & Holt, 2008), and auction (Choi, Brunet, How, 2009; Kivelevitch, Cohen, & Kumar, 2011) approaches are also used. These capabilities have been shown to reduce operator workload and the time required to generate solutions compared to performing these tasks manually. Human interaction with the CCA, however, is rather fixed. The operator identifies target locations and how many vehicles will be tasked and the CCA then provides a plan to be accepted or rejected by the operator. Since human operators may have mission goals such as plan-to-plan continuity or strict scheduling constraints that are not well aligned with the underlying CCA optimization metrics, a method for tuning or modifying CCA solutions is needed.

Human-Autonomy interfaces are needed that expose certain mechanizations and parameters of the CCA to the operator, increasing CCA transparency and flexibility over a large domain of missions. Flexibility implies that the operator has the ability to tune or modify generated play solutions, expanding beyond the "management by consent" mode of interaction. Using the same methods, IAs could also inform the operator of tuning possibilities and limitations given the current mission environment, and when circumstances are extremely dynamic or limitations preclude the operator from responding in a timely manner, the IAs could react by modifying the solution in a reasonable manner until additional direction is provided. This added flexibility will lead to more robust UxV mission performance, with algorithms that harness the efficiencies afforded by the CCA while providing more flexible control to the operator.

Intelligent Agents (IA)

The CCA requires that operators provide surveillance targets, available UxVs, mission objectives, and desired effects as initial inputs. The effectiveness of the CCA is jeopardized by two threats: (1) operators may not know which plays are ideal or even applicable in complex time-critical situations; and (2) to avoid re-planning, the CCA must adjust/adapt to local mission needs while adhering to a global mission solution. Intelligent agents can support the CCA by mitigating these threats and support operators by helping them call plays and failsafe reactions, while avoiding low-level UxV control.

An IA can assist operators by providing them with an analysis of alternative plays (i.e., an "assistant coach"). Operators, interacting with the agent through human-autonomy interfaces can accept suggested plays or compose their own. The IA uses domain knowledge and inferences about constraints and possible actions to assemble sets of contextually relevant plays. Using high-level representations of opportunities and goals, the IA bases play calling on knowledge and reasons operators understand.

Research efforts developing agent-based operator assistance capabilities are rare (Beer, Alboul, Norling, & Wallis, 2013). Independent researchers are investigating: constraint-based route planning and decision making (Ryan, 2010; Fargier, Lang, Martin-Clouaire, & Schiex, 2013; Todorovski, Bridewell, & Langley, 2012); knowledge tracing (Pirolli & Kairam, 2013; Sao Pedro, de Baker, Gobert, Montalvo, & Nakama, 2013); the use of abduction during analyses of alternatives (Menzies, 1996a; Menzies, 1996b; Russo, Miller, Nuseibeh, & Kramer, 2002; Garcez, Russo, Nuseibeh, & Kramer, 2003; Angius, 2013); and the effectiveness of constraint-based approaches in intelligent tutors (Diziol, Walker, Rummel, & Koedinger, 2010; Holland, Mitrovic, & Martin, 2009; Mitrovic, 2012; Suraweera, Mitrovic, & Martin, 2010). The IA combines features of these efforts and advances the state-of-the-art agent-based operator assistance. The IA is specified in the Research Modeling Language (RML), a modeling language tailored to the needs of IA authoring (Douglass & Mittal, 2011; Mittal & Douglass, 2011a; Mittal & Douglass, 2011b). The IA is executed in the Cognitively Enhanced Complex

Event Processing (CECEP) modeling and simulation framework (Hansen & Douglass, 2012; Taha, Atahary, & Douglass, 2013). The IA makes use of multiple objective functions during the process. These functions are used to develop a Pareto Front (Fundenberg & Tirole, 1983; Coello-Coello, Lamont, & Veldhuizen, 2007) that allows the IA to provide the operator with alternative plays sorted by estimated costs and payoffs.

Rainbow Autonomics Framework

While CCA and IA can help select plays, assign vehicles, and optimize routes, there is a need for automation to assist in monitoring the execution of plays. A modified version of the Rainbow Autonomics Framework (Lange, Verbancsics, Gutzwiller, Reeder, & Sarles, 2012; Lange, Verbancsics, Gutzwiller, & Reeder, 2012) can support the operator by monitoring the status of ongoing plays. For example, Rainbow can be used to monitor a vehicle's progress along a route against the plan to notify the operator if the vehicle is falling behind (e.g., due to a head wind). Rainbow has been enhanced with a mechanism allowing properties of modeled entities to be discovered rather than programmed, thereby allowing it to be used effectively in situations without full prior knowledge (Verbancsics & Lange, 2013).

Human Autonomy Interface

A key challenge for achieving UxV team decision superiority is the design of a new interface paradigm, as current HAI approaches fail to facilitate trusted, *bi-directional collaboration and high-level tasking* between operators and autonomy (Draper, 2007; Eggers & Draper, 2006; Rodas, Szatkowski, & Veronda, 2011). For joint human-autonomy teaming, the operator must maintain overall *situation awareness* not only of system status and mission elements but also the intent of the multiple systems themselves (Chen, Barnes, & Harper-Sciarini, 2011; Endsley, 1996). For situations in which the operator needs to drill into the autonomy, adjust its parameters, or override its operation, *intuitive controls* (Draper, 2007) are required. An even more critical design challenge is efficiently supporting collaborative *human-autonomy dialog* (Draper, 2007; Gao, Lee, & Zhang, 2006), enabling operators to monitor and instruct autonomy in response to dynamic environments and goal priorities. An effective human-autonomy dialog must involve providing cognitive support and coordination mechanisms with respect to a skills, rules, and knowledge framework (Rasmussen, 1990).

Additionally, the HAI needs to provide four support functions identified by Woods and Hollnagel (2006) to help realize an effective collaborative schema. This includes *observability* into the autonomy's processing to ensure a common mental model and that both understand who is doing what and when (Linegang et al., 2006). *Directability* support is required to establish respective human/autonomy roles in task completion, with this allocation dynamic to achieve the most effective division of cognitive functions for the current task at hand (Parasuraman, Sheridan, & Wickens, 2000). Support in terms of *directing attention* to required actions is useful. Finally, support is required for the operator's *shifting perspective* (Calhoun, Warfield, Ruff, Spriggs, & Wright, 2010; DiVota & Morris, 2012) in multi-system teaming. Interfaces that enable agile teams to benefit from maturing CCA, IA, and Rainbow are needed to provide mechanisms for the operator and autonomy to suggest, predict, prioritize, remind, critique, and/or caution each other via bi-directional collaboration. In this effort, novel displays and controls provide natural, intuitive visibility into autonomy. To increase *autonomy's transparency* and support *appropriate trust and reliance*, an Ecological Interface Design (Vicente & Rasmussen, 1992) approach that focuses on the automation's capabilities and limitations was used, as well as Lee's guidance to convey the system's 3P's (purpose, process, and performance; Lee, 2012). Speech (84 words that could be combined into 2160 potential phrases) and touch multi-modal controls provide the operator with the ability to flexibly interact with the autonomy at any time.

A key challenge is designing an interface that enables true collaboration for human-autonomy teams. One potential approach centers on the use of a compiled set of plans or “plays” that can be modified as needed. The goal of this approach is to minimize workload associated with assigning/tasking assets, much like a football team has an approved set of plays that facilitate task delegation by the quarterback team leader (Miller, Goldman, Funk, Wu, and Pate, 2004). The IMPACT interfaces employ this play concept along with enabling detailed adaptations. Using “*Plays*” operators can initiate a series of automated steps or tasks with a few verbal and/or manual commands, e.g., “air inspect on point alpha”. “*Tailoring*” is also provided whereby the operator can inform and/or modify the cooperative control algorithms and IAs during play calling as well as revising a play already in progress.

IMPACT Spiral 1

Figure 1 showcases how CCA (color coded yellow), IA (color coded green), HAI (color coded blue), and Rainbow (color coded orange) interact to support the operator. When a human operator initiates a play via the HAI, a play request is sent to the IA, which in turn queries the CCA for the time it would take each UxV that fits the play request constraints to get to the play location. CCA calculates this information and sends it back to the IA, which then generates a solution set. By default, the IA will then request a route plan for the UxV(s) it determined to be best to fulfill the play request. The CCA generates the route plan and it is then displayed graphically on the HAI. The operator can then accept, reject, or edit the play. If the play is accepted, the IA requests a plan to execute to account for the UxV’s movement while the operator deliberated. The CCA updates the plan and it is sent to the UxV to execute. Upon play execution, Rainbow monitors the UxVs progress against the plan.

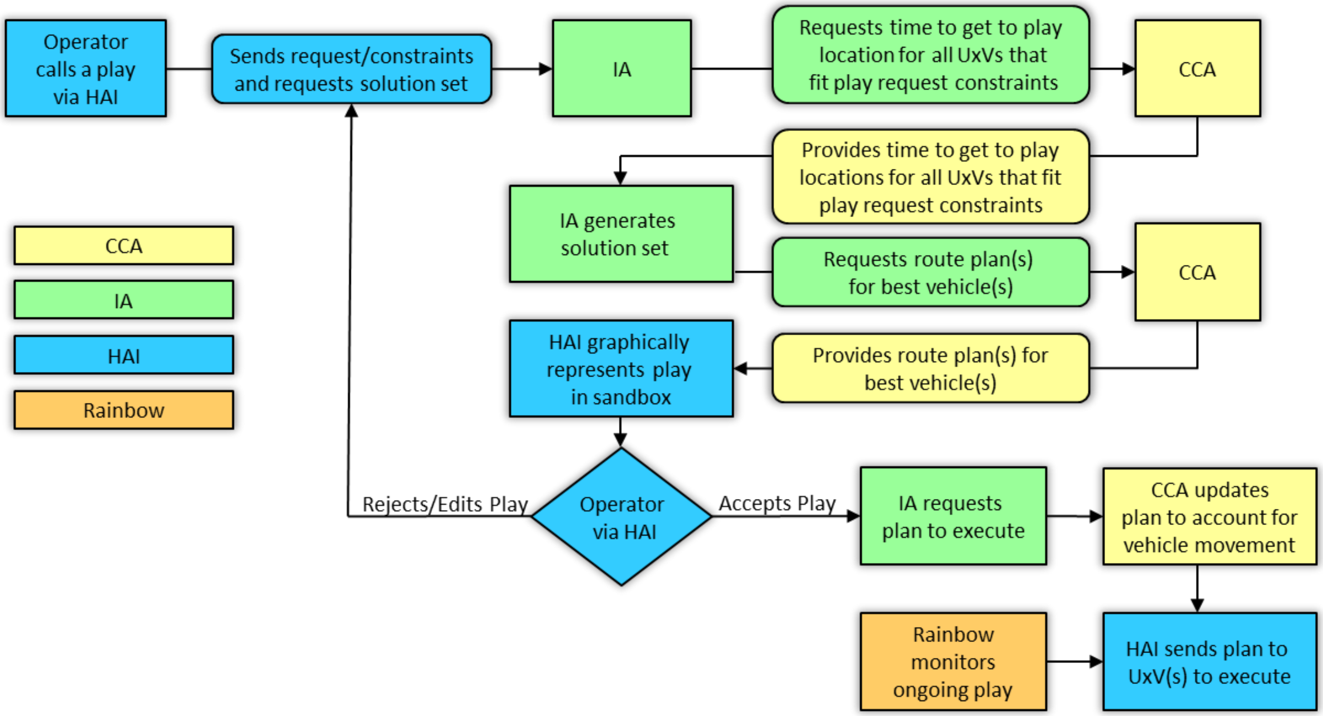

Figure 1. How IMPACT components interact in response to a play call.

To put this interaction among components in context, Figure 2 represents an operator responsible for controlling seven UxVs, tasked with providing surveillance at Point Charlie at night within 15 minutes (2a). The IA first determines which vehicles have the necessary capabilities (in this case an infrared (IR) sensor) to perform the task and eliminates those which don't (FN-18 and FN-20) from consideration (2b). The IA then sends a request to CCA to determine how long it would take each of the capable vehicles to reach Point Charlie and eliminates the vehicles that can't reach Point Charlie in time (FN-13 and FN-15) from consideration (2c). Next, the IA considers how long each vehicle can remain at Point Charlie based on fuel burn rate and fuel level and selects the vehicle (FN-12) that can remain the longest (2d). The IA then sends a request to CCA to plan a route for FN-12 to reach Point Charlie (2e), which the operator accepts. Finally, as FN-12 travels to Point Charlie the Rainbow Autonomics framework monitors the situation and notices a popup restricted operating zone (ROZ) that requires FN-12 to change its route (2f).

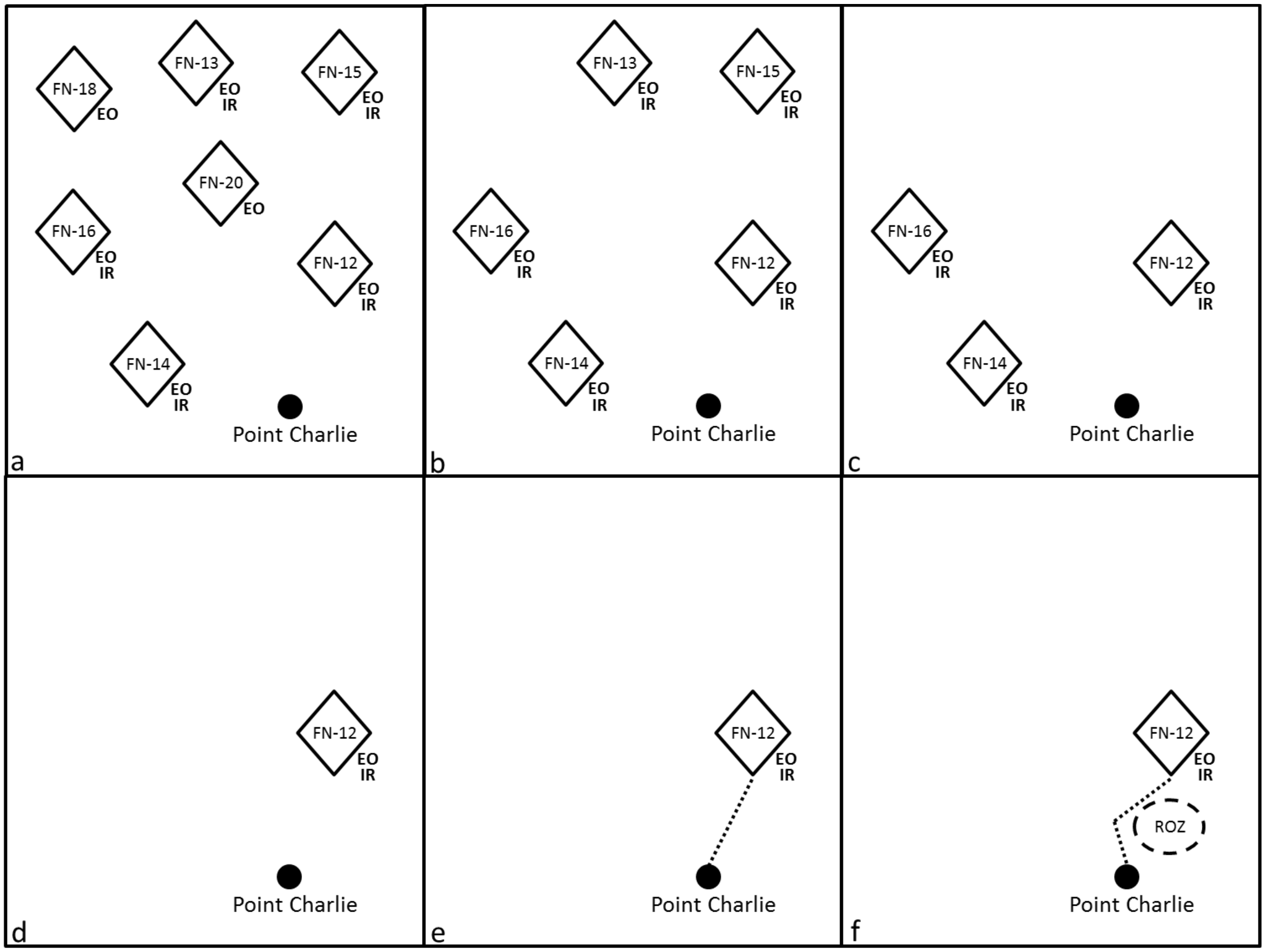

Figure 2. An example of how IMPACT components recommend a vehicle, plan a route, and monitor task status.

The present evaluation was designed to solicit feedback from UxV operators and base defense subject matter experts on the Spiral 1 IMPACT system that integrates human-machine interfaces, CCA, IA, and the Rainbow autonomics framework in the context of a base defense mission. This feedback will be used to inform the development of the Spiral 2 IMPACT system.

3. METHODS, ASSUMPTIONS AND PROCEDURES

Participants

Seven volunteers from Wright-Patterson Air Force Base (WPAFB) participated in the study. Three participants had prior experience flying UAVs (Predator, ScanEagle, Global Hawk, and Shadow) as well as manned aircraft (F-111, C-130, T-38, T-1, and RF-4). Four participants were active Air Force security force personnel with experience in conducting base defense operations in deployed environments (Afghanistan, Germany, Iraq, Kuwait, and Saudi Arabia). Relevant for this evaluation, one UAV operator had experience using a ScanEagle to support base defense missions. All participants were male and reported normal or corrected-to-normal vision, normal color vision, and normal hearing. Test procedures were approved by the Air Force Institutional Review Board and all participants provided informed consent prior to participation.

Equipment

The IMPACT test bed used the Fusion software developed by AFRL 711HPW/RHCI (for an in-depth description of Fusion, see Rowe, Spriggs, & Hooper, 2015). The IMPACT test bed used six computers (Single Dell T5610 & 4 Dell R7610's running Windows 8.1). One computer ran the HAI, the IA, the CCA, the Rainbow Autonomics framework, and the AMASE [AVTAS (Aerospace Vehicle Technology Assessment and Simulation) Multi-Agent Simulation Environment] vehicle simulation (used to simulate the UxVs). One computer ran the test operator console and simulation for simulated entities in the sensor videos (Vigilant Spirit Simulation; Feitshans & Davis, 2011), three computers ran two simulated sensor videos each (SubrScene Image Generator; www.subrscene.org/), and one computer ran an XMPP (Extensible Messaging and Presence Protocol) Chat server for simulated communications. The IMPACT test bed interface used four 27" touchscreen monitors (Acer T272HUL), a headset with a boom microphone (Plantronics GameCom Commander), a foot-pedal (for push-to-talk speech control), and a mouse and keyboard.

An overview of the IMPACT test bed interface is shown in Figure 3. Starting with the top screen and moving clockwise, the Tactical Situation Awareness Display provided a geo-referenced map with UxV locations as well as UxV-specific information (e.g., a UxV's current play, error indicators, a UxV's planned route, etc.). The Payload Management display showed available sensor feeds on demand and will include other payloads (e.g., weapons, communication devices, etc.) in the future. The Sandbox display was a workspace for the operator to call and edit plays without obscuring the current state of the world (which was always available in the Tactical Situation Awareness Display). Finally, the System Tools display contained chat windows as well as help documentation (e.g., list of voice commands).

Figure 3. A screenshot of IMPACT's test bed interface, with the tactical situation awareness display on the top monitor, the payload management display on the right monitor, the sandbox (planning area) on the bottom monitor, and system tools on the left monitor.

IMPACT Spiral 1 Human-Autonomy Interface

The ensuing section provides a high-level description of the IMPACT Spiral 1 play calling interface (see Calhoun, Ruff, Behymer & Frost, in press for a description of the Spiral 2 interface). The IMPACT operator was responsible for six UxVs during the Spiral 1 evaluation (see Figure 4): three UAVs (call signs FN-41, FN-42, and FN-43; represented by the diamond shaped icons), two UGVs (call signs TR-11 and TR-21; represented by the tombstone shaped icons) and one USV (call sign SY-41; represented by the pentagon shaped icon).

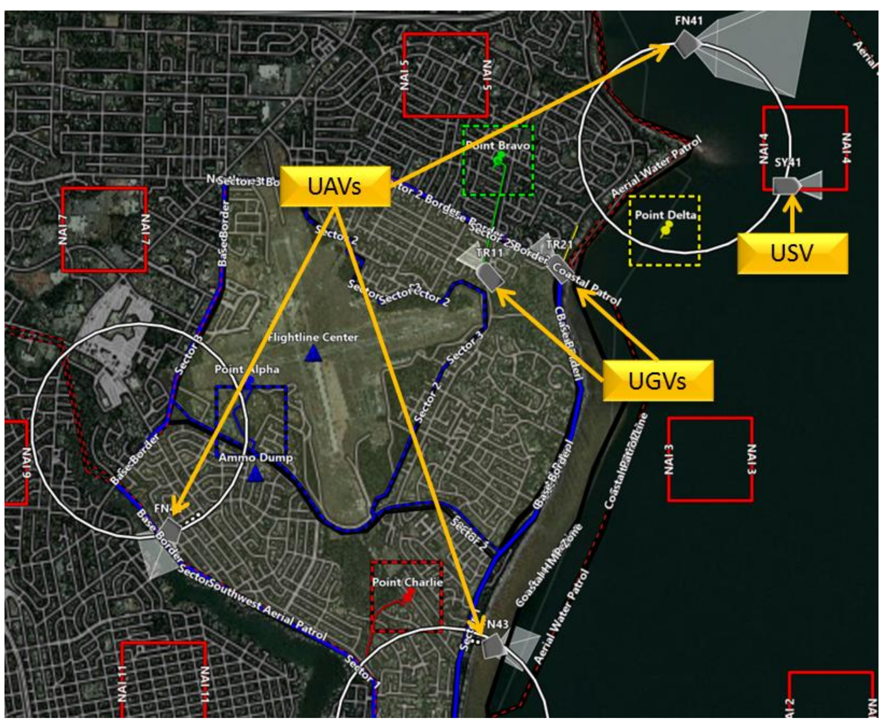

Figure 4. UAV, UGV, and USV icons displayed on the tactical situation awareness display.

In Spiral 1, operators initiated plays by clicking or touching one of thirteen icons in the Play Creator interface (see Figure 5a), each of which corresponded to a specific play. For example, to call an air surveillance at a point, operators clicked or touched the leftmost icon in the first row. Operators could also initiate plays by using the voice command (e.g., "air surveillance") associated with each play. Once a play was initiated, operators selected a play location from a dropdown menu of previously identified points or created a new point by clicking on the map (see Figure 5b).

(a) (b)

Figure 5. Play Creator Tile. (a) icons for each of Spiral 1's thirteen plays. (b) methods for identifying a location including selecting any point on the map or selecting an existing location via a dropdown menu.

Once the operator selected a point (e.g., Point Alpha), the IA sent a request to CCA asking the time it would take each UAV to reach Point Alpha, and by default recommended the UAV that would arrive soonest, in this case FN-42 (see Figure 6).

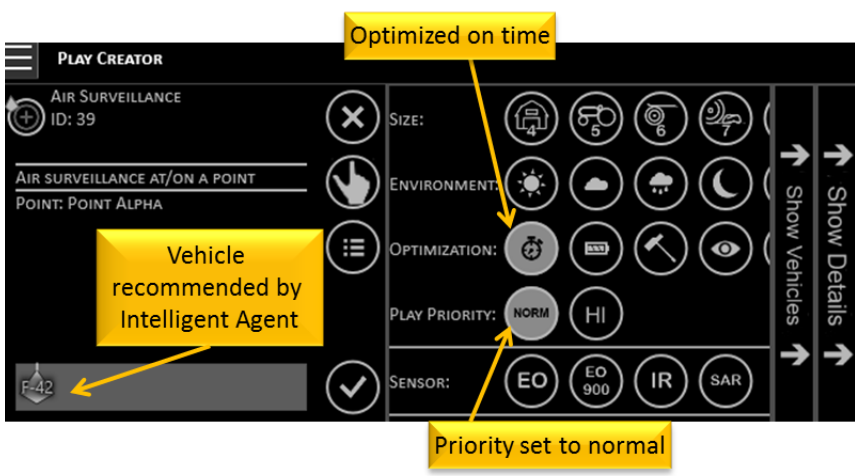

Figure 6. Play Creator Intelligent Agent Reasoning — the operator has asked the Intelligent Agent to optimize for time (the stop watch icon is selected) and has set priority to normal, which allowed the Intelligent Agent to recommend the optimal vehicle based on these presets.

Additionally, the CCA planned route from FN-42's current location to Point Alpha was represented on the map with a dashed line (see Figure 7). Each potential play was given a unique play color (in this case orange).

Figure 7. Planned route for FN-42 to Point Alpha (represented by a dashed orange line).

The operator had the option to override the IA's recommendation by manually selecting a vehicle using the Play Creator's vehicle panel. In Figure 8, the operator manually selected FN-41 to complete the task and CCA immediately planned a route from FN-41's current location to Point Alpha, again represented by the dashed orange line (see Figure 9).

Figure 8. Play Creator Tile manual vehicle selection — the operator has opened the manual vehicles panel and selected FN-41.

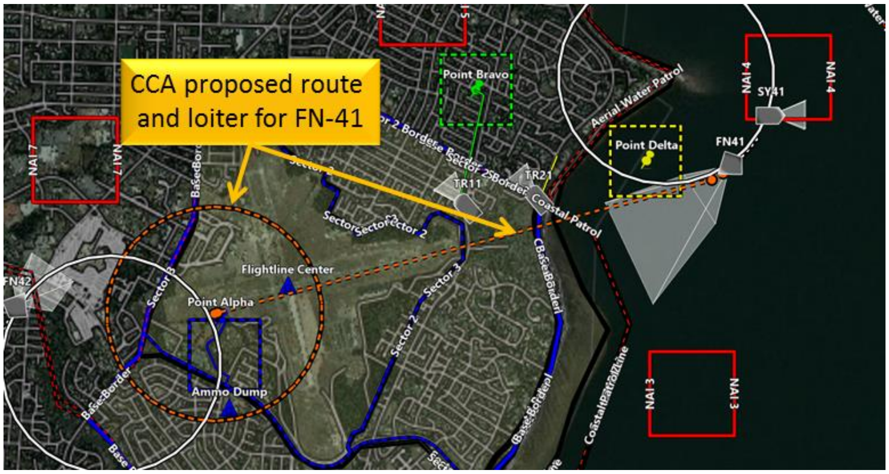

Figure 9. Planned route for FN-41 to Point Alpha (represented by a dashed orange line).

The operator also had the ability to improve the IA's recommendation by providing updated situation information. For example, if FN-41's Sensor Operator reported heavy cloud coverage at Point Alpha, the IMPACT operator communicated this to the IA by selecting the cloud icon in the Play Creator and the IA now recommended FN-43, which has an IR sensor (see Figure 10) and CCA planed a route for FN-43 to get to Point Alpha (see Figure 11).

Figure 10. Operator providing information to the Intelligent Agent including enviromental conditions (the cloud icon is selected), optimization preference (the stopwatch icon is selected), and prioirty (normal is slected). The Intelligent Agent has recommened FN-43 (which has an IR sensor) based on these operator inputs.

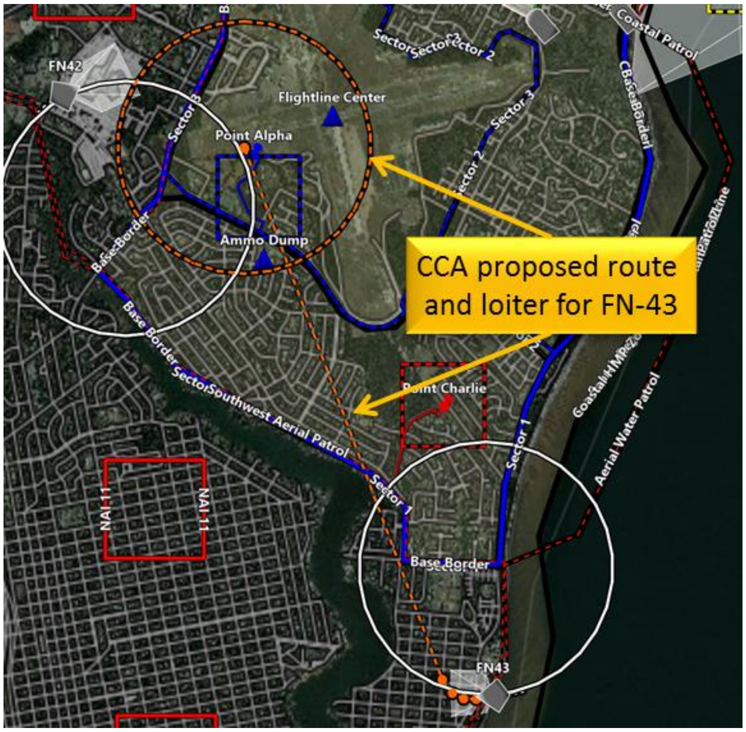

Figure 11. Planned route for FN-43 to Point Alpha (represented by a dashed orange line).

The operator could also edit route details manually using the Play Creator's details panel (see Figure 12). In this example the operator has changed the loiter length to 1500 meters, creating a racetrack loiter pattern (see Figure 13).

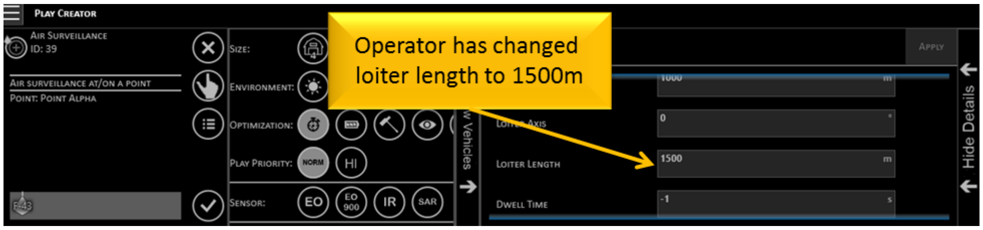

Figure 12. Play Creator details panel — the operator has opened up the details panel and changed the loiter length to 1500 m.

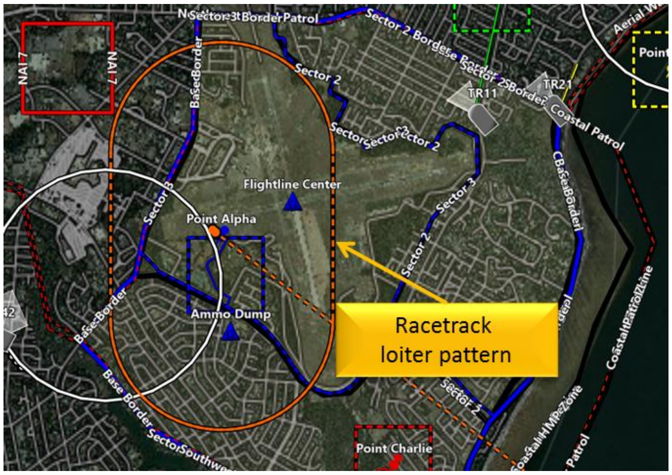

Figure 13. Racetrack loiter pattern (represented by the dashed orange line).

Once modifications were completed, the operator could click the checkmark to accept the plan and FN-43 would begin to execute it, with the change from plan to reality represented by the dashed line becoming solid and FN-43's icon changing to orange (see Figure 14).

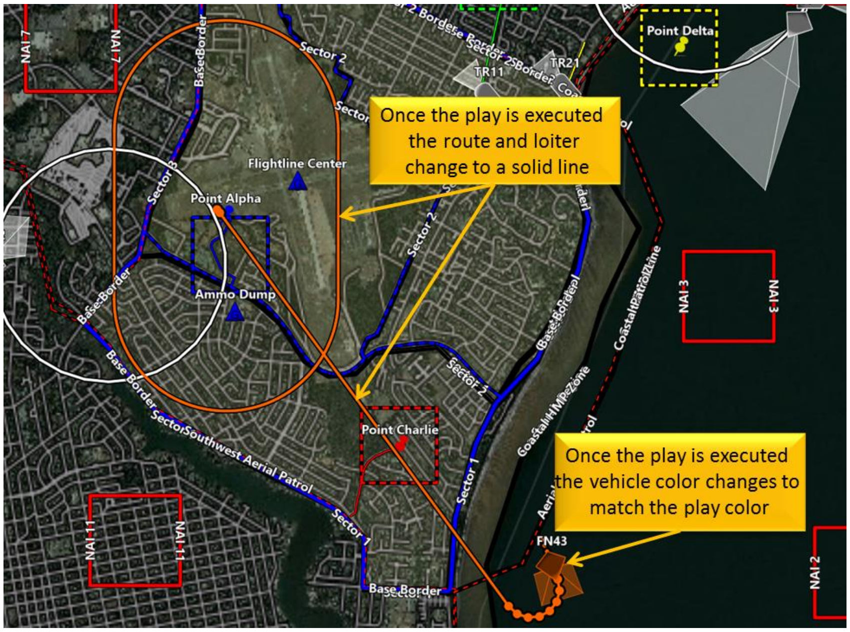

Figure 14. Plan Execution (the dashed orange line has changed to solid and the vehicle color has changed to orange now that the play is executing).

Additionally, an Active Play Manager (see Figure 15) opens and lists the plays that are currently executing. Once a play is active the Rainbow Autonomics framework monitors the play's progression and checks to see if FN-43's estimated time enroute (ETE), fuel state, and dwell time (how long FN-43 can remain at Point Alpha) are going as planned.

Figure 15. The Active Play Manager provides a list of all ongoing plays.

Clicking a play within the Active Play Manger opens a window that provides status information about the play (Figure 16; see Behymer, Ruff, Mersch, Calhoun, & Spriggs, 2015 for additional details). This chart conveys several pieces of information to the operator. In the bar chart, the parameters were ordered from left to right based on their priority, with the highest priority parameter at the far left. The width of each column also represented the priority of each parameter. For example, estimated time enroute (ETE) was given the most weighting, followed by fuel and dwell time. Color is used to represent a play's status. If everything is going according to plan (e.g., the UV is still expected to arrive at task location on time) the middle segment of that parameter's column is green and indicates a "normal/ideal" state. A warning state is represented with three yellow segments and indicates a "slight" deviation from the ideal state. An error state is represented with five red segments and indicates a "severe" deviation from the ideal state. The specific location of the segment with the brighter, more saturated color indicates whether the value exceeds or is less than the desired operating range for that parameter.

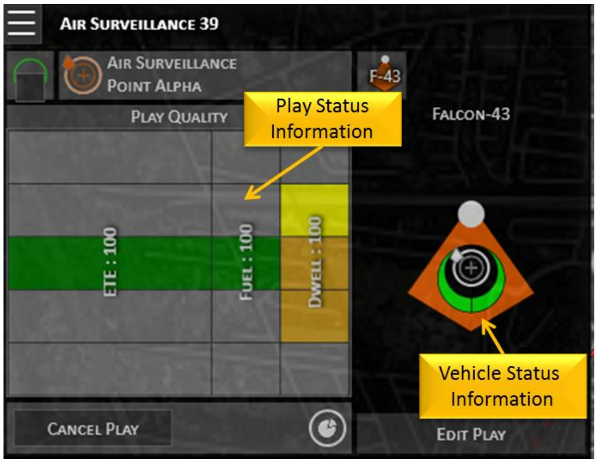

Figure 16. Clicking a play in the Active Play Manager opens up an additional tile containing detailed play and vehicle status information.

Procedure

Participants completed a background questionnaire (see Appendix A) and were given an overview of the IMPACT test bed. The overview included a slideshow that described the project's goals and introduced the concept of play calling. Next, participants were seated at the IMPACT test bed and given an overview of their mission that included:

- A description of the UxVs they would be controlling, how each UxV, its route, and its sensor footprint were represented on the map, and the tasks that each UxV was responsible for performing in support of base defense operations.
- An overview of the base they would be defending including the base's perimeter, sectors, critical facilities, patrol zones, and the named areas of interests in the area immediately surrounding the base.
- An overview of their role as a multi-UxV operator supporting base defense operations that described that they would be assigning high-level tasks to the UxVs while the autonomous system components flew, drove, and steered the UxVs. Also, that they would be assigned tasks from their commander in a chat window and that they would have access to the UxV sensor feeds but it was not their responsibility to monitor them.

The experimenter then provided the participant with a high-level description of the IMPACT test bed's layout (similar to the above description of Figure 3). Next, the experimenter explained the following IMPACT components while the participant sat at the controls performing each function.

- *Chat Window*: the location of the chat window, how to send and receive chat messages, audio alerts associated with incoming chat messages, how to resize the chat window, how to change the font size of the chat window's text.
- *Play Creation Tile* (described above in Figure 5a): how to call plays, how play types were categorized by row (e.g., the first row contains plays focused on points, the second on routes, the third on areas, the fourth on sensors, and the fifth on custom plays like normal full coverage and highly mobile), how hovering over a play icon will provide the play's name, how to specify a play location, specific vehicles, constraints, and details.
- *Play Icon Symbology:* how the play's type is represented by a shape within the play icon (e.g., plus sign for point plays, lines for route plays, squares for area plays, and a sensor footprint for sensor plays), how the unmanned vehicle type associated with a play is represented by a shape/location (UAVs – upper left/diamond, UGVs, lower left/horizontal rectangle, USV – lower right/vertical rectangle).
- *Play Calling:* how plays could be called by clicking/touching a play icon in the play creation tile or by using a voice command. Participants were trained on how to activate the speech recognition system (pushing a foot pedal or clicking/touching a bar on the bottom of the sandbox) as well as how the speech recognition system provided feedback (verbally over the headset as well as text on the screen).
- *Play Tile:* how information about a play's progress could be obtained, how plays could be edited.
- *IA Recommendations:* how the IA would recommend a play if a UxV was near a critical facility.

Next, participants were trained on calling plays using each modality (mouse and keyboard, touch, and voice) in order to familiarize them with each method of play calling. Participants received 12 chat messages (e.g., "Using voice, call an air surveillance at Point Alpha") asking them to call a play using a specific modality (4 plays for each modality). A list of voice commands was available to the participants on the left monitor. Table 1 lists the exact sequence of plays participants were asked to call during this portion of the training as well as the modality participants were instructed to use for each of the 12 plays.

Table 1. Play Calling Modality Training

Method	Play
Voice	Air Surveillance at Point Alpha
Voice	Normal Full Coverage Patrol
Voice	Ground Inspect at Route Bravo
Voice	Air Expanding Square Search at Point Charlie
Touch	Air Sector Search at Point Alpha
Touch	Surface Parallel Search at Area Delta
Touch	Air Parallel Search at Area Bravo
Touch	Ground Inspect at Point Charlie
Mouse	Air Ground Surveillance at Point Bravo
Mouse	Air Inspect at Route Charlie
Mouse	Air Surface Parallel Search at Area Delta
Mouse	Go Highly Mobile at Point Alpha

Participants were then trained on how to specify constraints, vehicles, and details when calling and/or editing a play. For each modality, participants were asked via chat message to call a specific play (e.g., "Using voice, call an air surveillance on Point Alpha, set sensor to EO, and optimize for low impact"), then make edits to the ongoing play (e.g., "Change the loiter type to a figure 8"). The exact sequence of the play calls and play edits participants were asked to make is listed in Table 2. If a participant made a mistake, the experimenter provided feedback and the participant tried again until he had successfully completed the correct action. On average, training lasted 1 hour. Before continuing, participants took a short break that was also used to reset the test bed for the mission simulation.

Table 2. Play Editing Training

Method	Play Call or Edit
Voice	Air Surveillance on Point Alpha with EO that minimizes impact to other plays
Any	Edit– Change loiter type to figure 8
Any	Edit– Change standoff distance to 2000 m
Any	Edit– Change visibility to obscured
Any	Edit– Change loiter type to race track, change standoff distance to 0 m, change visibility to clear, and change loiter length to 1000 m
Mouse	Expanding Square Search at point bravo, size 5, cloudy, minimize fuel
Any	Edit– Change extent to 1500 m
Any	Edit– Change vehicle to a different UAV
Any	Edit– Change extent to 2000 m and select SAR sensor
Touch	Air Parallel Search at Area Delta
Any	Edit– Change the air vehicle to a different UAV
Any	Edit– Change the sweep angle to 30 degrees
Any	Edit– Change the sensor to IR and the visibility to obscured

Mission

The purpose of the mission was to exercise IMPACT capabilities within a realistic context. To achieve a realistic simulation, the mission scenario was developed based on the results of a cognitive task analysis (CTA) conducted prior to the study. Three CTA methods were used to gain an understanding of current base defense operations as well as how operators might integrate UxVs into their operations. First, the task diagram method (Militello, Hutton, Pliske, Knight, Klein, & Randel, 1997) was used to elicit the major job components of base defense personnel and identify the major cognitive challenges base defense personnel face. Next, the critical decision method (Klein, Calderwood, & MacGregor, 1989) was used to identify critical incidents that security forces had experienced in order to inform the development of realistic scenarios for the evaluation. Finally, the simulation interview method (Militello, Hutton, Pliske, Knight, Klein, & Randel, 1997) was used to investigate how security force personnel would use UxVs in the context of a notional base defense scenario. Using PowerPoint slides, experimenters provided interviewees with a mock base and asked them how they would defend it using current methods (i.e., without UxVs). Experimenters then briefed participants on the capabilities of a UAV (Boeing's ScanEagle), an unmanned ground vehicle (General Dynamics Mobile Detection Assessment and Response System [MDARS]), and an unmanned surface vehicle (BAE System's Protector) and asked how they would incorporate these vehicles into the base defense operations for this notional base. Interviewees were then given a series of simulated events (e.g., a crowd is forming outside a base gate, a HUMINT (human intelligence) report of a military age male carrying a mortar within 10 miles of the base) and asked how they would respond to the events using UxV assets.

Prior to the mission, participants were given a pre-mission brief that informed them that their tasks would be to call plays in response to chat messages from their remotely located commander and sensor operator, played by confederates. Participants were also informed that the scenario would begin with a UAV investigating a suspicious watercraft and all other UxVs on high alert (i.e., a highly mobile patrol pattern). Table 3 lists the exact sequence of mission events that occurred. Participants were instructed to respond to chat messages as soon as possible and were free to respond to commander and sensor operator requests with the play (called with the modality of their choice) they felt best achieved the commander/sensor operator's goal. The mission lasted approximately 20 minutes.

Table 3. Sequence of Mission Events

Mission Events
1. Operator receives a chat message from the Sensor Operator that the unidentified watercraft is a fishing boat.
2. Operator receives a chat message from the Commander to resume normal base defense operations/patrols.
3. The IA recognizes a serendipitous surveillance opportunity (a UAV is near a critical facility) and recommends a play (air surveillance at the critical facility) to the operator.
4. Operator receives a chat message from the Commander to send a UAV to Point Charlie and to instruct other UxVs to go highly mobile in response to a patrol reporting smoke at Point Charlie.
5. Operator receives a chat message from the Sensor Operator to send a UGV to Point Charlie to get a better look.
6. Operator receives a chat message from the Commander to provide the UGV headed to Point Charlie with a UAV overwatch.

Once the mission was finished, participants completed paper questionnaires on the overall IMPACT system (see Appendix B) and its components (see Appendix C). Then, a semi-structured interview (see Appendix D) was conducted to: capture additional feedback on IMPACT and the associated technologies, solicit feedback on the scenario and base defense domain, and debrief participants. Finally, participants were briefed on additional IMPACT interface features and concepts that were under development but not yet integrated. Participants were asked to provide input/feedback on the components' designs for refinement prior to integration (input/feedback on components not integrated into Spiral 1 are outside the scope of this report). The questionnaires, interview/debrief, and slideshow presentations lasted 100 minutes on average. The entire procedure lasted approximately 3.25 hors overall.

4. RESULTS

Of the seven individuals who participated in the study, six completed the training and mission in the allotted time. Due to unanticipated time restrictions, the seventh participant was unable to complete the study and was eliminated from the data analysis. Due to the small number of participants, UV operators and Security Force personnel data were not analyzed separately. In general, the UV operators had more suggestions on improving IMPACT's HAI and autonomous components while Security Force personnel had more suggestions on improving the mission scenario.

Overall System

Participants used a 5-point Likert scale (ranging from 1: No Aid to 5: Great Aid) to rate IMPACT's potential value for future UxV operations as well as the ability of IMPACT to aid operator workload and situation awareness (see Figure 17; note that the vertical line is the scale's midpoint, so all ratings to the right are above a 3). Participant responses indicated that they had a positive opinion on the potential value of IMPACT for future UxV operations, to aid workload, and to aid situation awareness, with no ratings less than a 4.

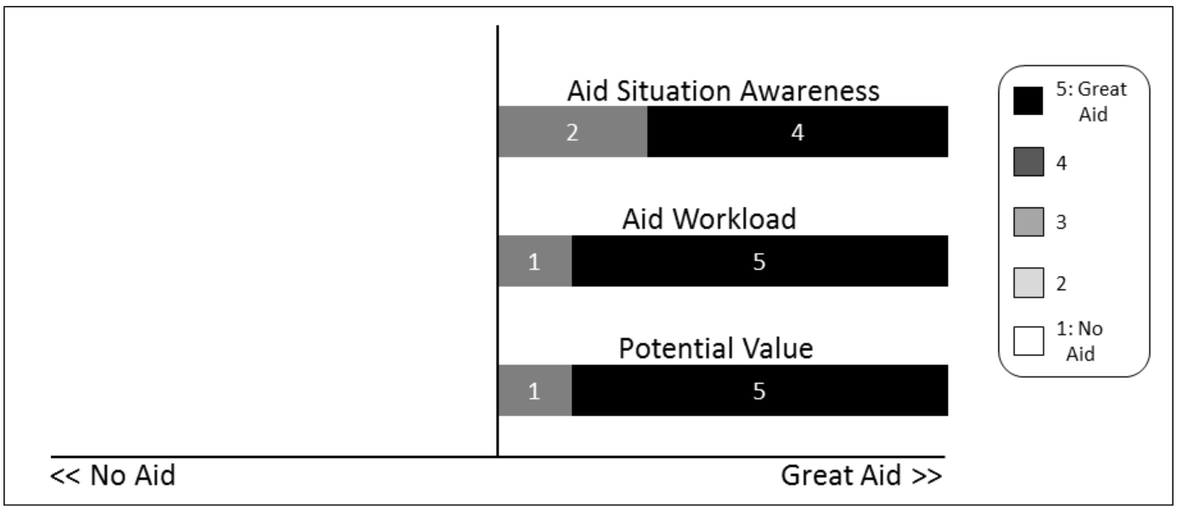

Figure 17. Participant ratings for IMPACT's ability to aid situation awareness, workload, and potential value to future UxV operations. Every participant rated IMPACT at a 4 or higher for each of the three measures. The numbers inside the bars indicate the number of participants who provided a rating at that scale value.

The overall usability of IMPACT was assessed using the System Usability Scale (SUS; Brooke, 1996). The SUS asks participants to evaluate 10 items related to system usability using a 5 point Likert scale ranging from Strongly Agree to Strongly Disagree (see Figure 18), and these 10 items contribute to an overall SUS score. The overall mean SUS score for IMPACT was 73.75, placing it in the 70th percentile of SUS scores.

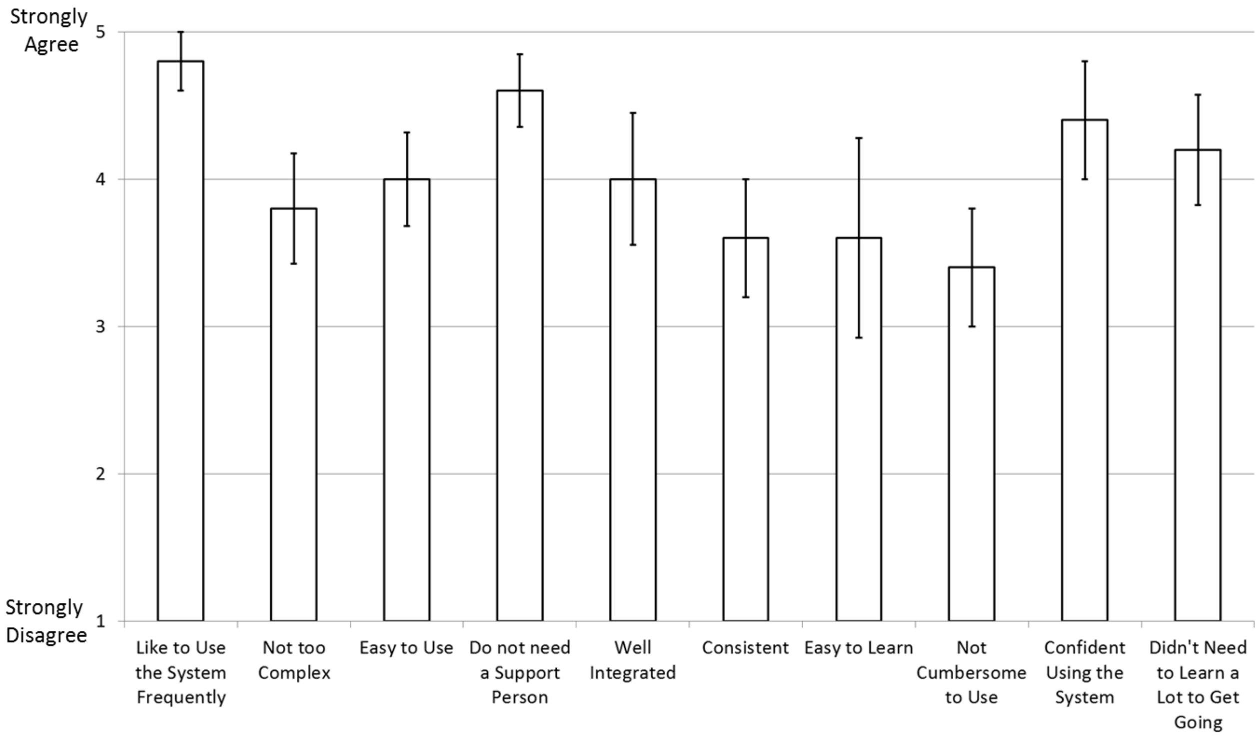

Figure 18. System Usability Scale Results. (Error Bars are the Standard Errors of the Means)

Participants were also asked what they most liked, what they least liked, what was most confusing, and what they would improve in regards to the overall IMPACT system (see Table 4).

Table 4. Participant Comments on the Overall System

Most Liked	Least Liked	Most Confusing	Improvements
• Multiple modalities (e.g., speech, touch, keyboard and mouse) • Agent recommending plays when a UV is near a critical facility • Play Creation tile's intuitive symbology • Ability to maintain big picture on top screen while zooming in and planning on bottom screen (sandbox)	• Touch screen wasn't precise enough; difficult to select correct button • Cannot manually draw routes for UxVs • Displaying all UxV routes made the map cluttered • Requiring confirmation to execute a play	• Difficult to determine where a specific UxV was going due to map clutter (e.g., vehicle routes, vehicle loiter patterns) • Challenge to learn how play icons were organized in Play Creator tile	• Ability to call plays by clicking locations/vehicles on the map • A single ear headset would be more comfortable and help maintain situation awareness • Expand voice commands to more than just play calling • Forecasting capabilities (e.g., what are things going to be like in 10 minutes)

In addition to rating the overall IMPACT system, participants were asked to rate four system components (Play Calling, Autonomy, Feedback, and Test Bed) on five parameters (Potential Value, Ease of Use, Integration, Consistency, and Ease of Learning) and provide any comments they had about each component. The results for each system component are described below, accompanied by a high-level summary of participant comments. Overall, 88% of ratings were either a 4 or 5 (the top two categories) and only a single component (Ease of Learning of Feedback) was rated less than a 3.

Play Calling

Participants were asked to rate the HAI components that allowed them to issue high level plays to one or more UxVs including the play creator tile (Figure 5a), play creation work-flow (Figure 6), preset panel (Figure 10), selecting a play location (Figure 5b), selecting a play vehicle (Figure 8), modifying play details (Figure 12), and confirming the play (Figure 14). Participants rated all five parameters positively (see Figure 19).

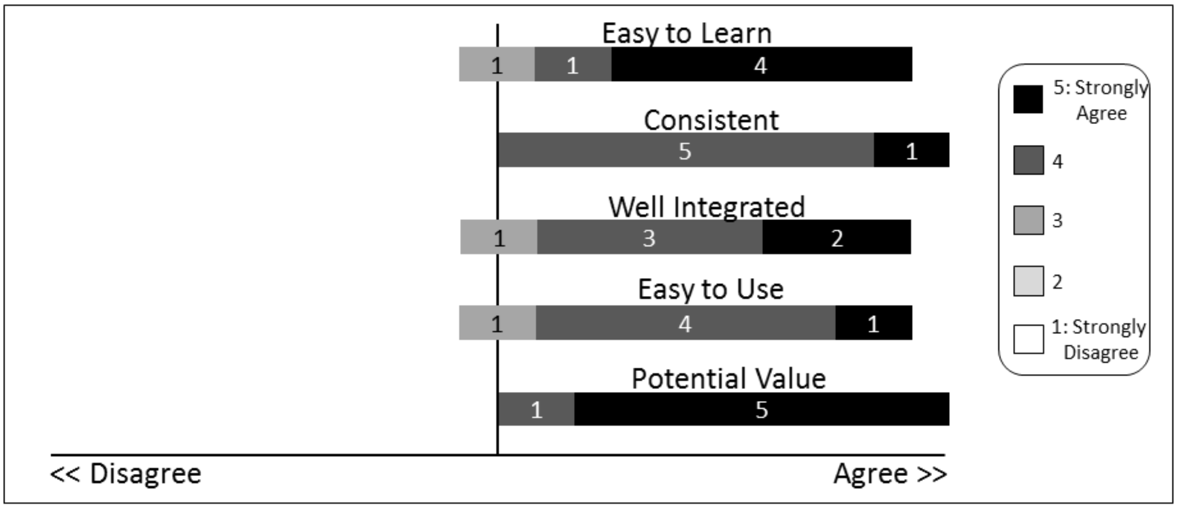

Figure 19. Participant Ratings for Play Calling — 90% of participant ratings across the five measures were 4 or higher. The numbers inside the bars indicate the number of participants who provided a rating at that scale value.

In general participants responded positively to the Play Creator tile icon symbology (Figures 5a and 6), commenting that the symbols were more intuitive and easier to learn than a text-based menu system. In fact, one participant even suggested replacing the text fields in the details panel (Figure 12) with a symbology based approach. Participants made several recommendations for improvements including organizing play icons by vehicle type (e.g., all UAV plays in the first row, UGV plays in the second row, etc.) instead of by play type (e.g., all point plays in the first row, route plays in the second row, etc.), adding a visual indicator when a play detail has been modified from the default setting, and adding a warning before closing a play during editing if the changes have not been executed (i.e., sent to the UxV).

> "*I do like the heavy reliance on symbology. The learning curve is quicker. Less numbers and words is good.*" – UAV Operator

Autonomy

Participants were asked to rate the IMPACT's autonomous components, including the automated route planning (CCA), vehicle and play recommendation features (IA), and play monitoring (Rainbow). Participants generally rated all five parameters positively (see Figure 20).

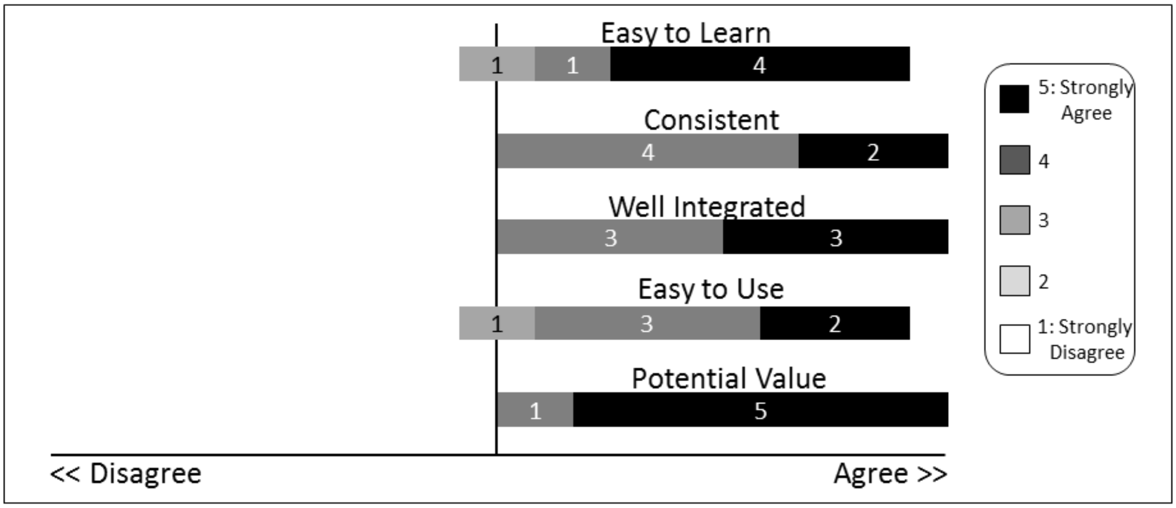

Figure 20. Participant Ratings for IMPACT's Autonomous Capabilties — 93% of participant ratings across the five measures were 4 or higher. The numbers inside the bars indicate the number of participants who provided a rating at that scale value.

> *"I find myself falling into, and it may be a trap or it may be not, of trusting the system. Partly I was inherently believing that it was going to be a good solution, and it wasn't easy to double check what was going on."* – UAV Operator

Overall, participants commented favorably on IMPACT's autonomous capabilities, citing IA vehicle and play recommendations as particularly valuable. However, participant comments reflected that they often felt disconnected from the IA's reasoning process. For example, if the operator selected both the cloudy optimization preset and the EO sensor preset the IA wouldn't provide a recommendation because it was impossible to generate a plan that could fulfill both these constraints. Unfortunately, the operator only received a message that the play request was over constrained, not **why** the request couldn't be fulfilled. Additionally, several participants were unsure how they could evaluate the IA's recommendations as they received no feedback on why the IA had recommended one vehicle over another to fulfill a play request. Finally, some participants suggested that providing multiple courses of action to choose from may be preferable to providing a single course of action in some situations.

Feedback

Participants were asked to rate IMPACT’s ability to provide feedback on play status via the Active Play Manager (Figure 15) and the Play Status Tile (Figure 16). Participants generally rated all five parameters positively (see Figure 21).

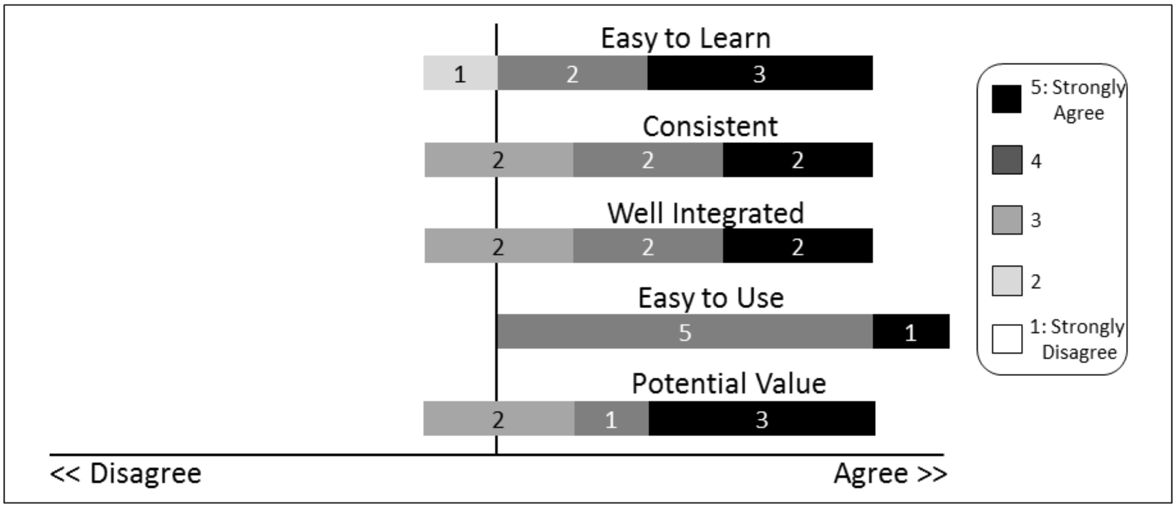

Figure 21. Participant Ratings for IMPACT's Feedback System — 76% of participant ratings across the five measures were 4 or higher. The numbers inside the bars indicate the number of participants who provided a rating at that scale value.

Participant comments were positive in regards to the feedback provided by IMPACT’s HAI, especially the Active Play Manager, which participants felt helped maintain their situation awareness despite having a map cluttered with six UxV routes. Participants made several recommendations for improving the Active Play Manager including providing play status information instead of needing to drill down to the Play Status Tile (Figure 16) and using it to center the map on plays.

> *“When the map was real complicated and busy the Active Play Manager made it real easy for me to go through and tell what the different pieces were doing.”* – UAV Operator

Test Bed

Finally, participants were asked to rate IMPACT’s test bed, which included the map, screen and interface layout, speech, touch, and keyboard and mouse input modalities, and the chat system. Once again, generally all five parameters were rated positively (see Figure 22).

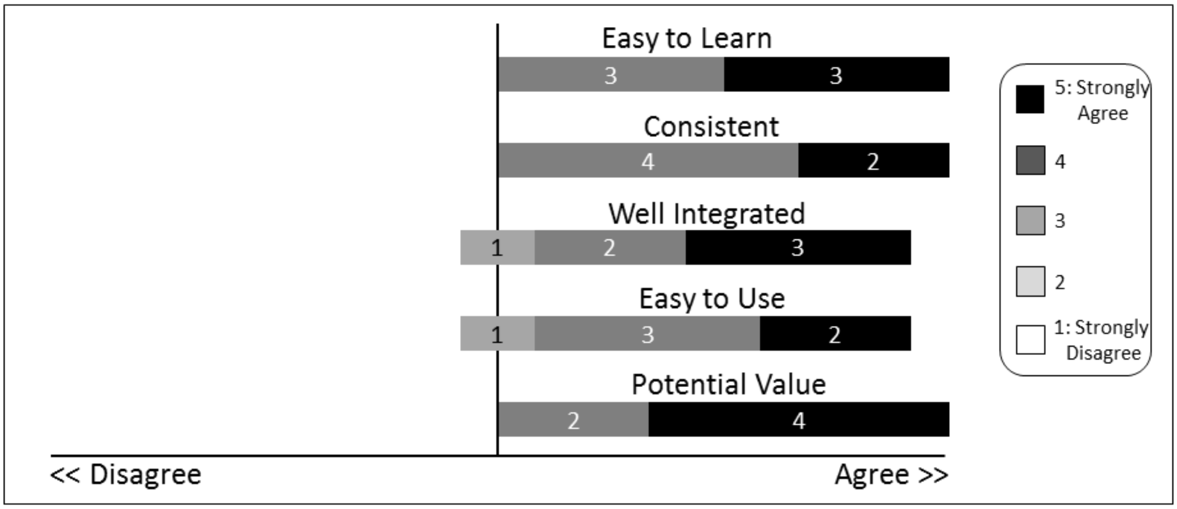

Figure 22. Participant Ratings for the IMPACT Test Bed — 93% of participant ratings across the five measures were 4 or higher. The numbers inside the bars indicate the number of participants who provided a rating at that scale value.

> *"You don't get a lot of focus, kind of lose track of who's doing what and what's doing what."* – Security Force Specialist

Almost every participant mentioned that the map became cluttered when certain plays (e.g., sector search – see Figure 23) were called. Several participants suggested that it was difficult to connect what they were doing in the Play Creation Tile with what was happening on the map. Participants also expressed a desire to interact directly with the map to call plays by dragging UxV icons to a location.

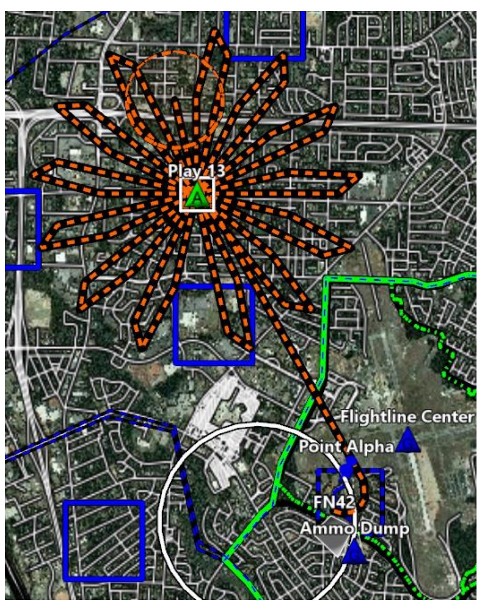

Figure 23. An example of the sandbox display being cluttered during planning for a sector search play.

The feedback on touch and speech was mixed; in general, participants seemed to like the idea of being able to execute plays via touch and speech. However, participants expressed concerns about the touchscreen's calibration and lack of precision (a participant might touch an icon three times before the system registered it) and the speech system's poor accuracy (the word error rate was 21.95%). Objective data was also collected on the modality (mouse, touch, or speech) that participants used to call plays during the mission (when participants could choose the modality). Though several participants had positive comments about speech and touch, participants tended to use the mouse more than touch or speech (see Figure 24 – note that speech is labeled speech/mouse because when participants used speech during the mission they always used it in conjunction with the mouse. For example, a participant would initiate a play call with a speech command but execute the play by clicking the checkmark with the mouse instead of saying "Confirm" to execute the play by speech command). In fact, only one participant tried to use the touchscreen to call plays during the mission and only two participants tried to use speech. Participants also made a higher percentage of major errors (defined as failing to complete a play correctly) when using touch than mouse or speech (see Figure 24).

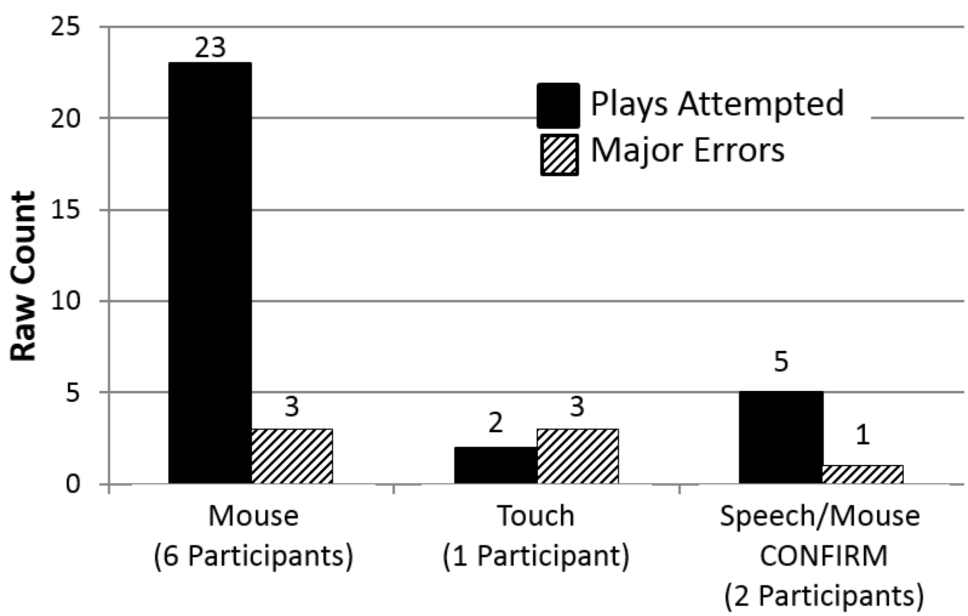

Figure 24. Number of plays attempted and number of major errors by modality type.

Participants were also faster at completing plays using the mouse as compared to using touch or speech (see Figure 25). However, this difference most likely reflected the specific problems participants had with the touch (not precise enough) and speech (not accurate enough). In fact, when only correctly completed plays (i.e., no major errors) were examined the difference between time to complete a play with the mouse and speech was only 2.5 seconds (see Figure 26 – note that participants never correctly completed a play using touch).

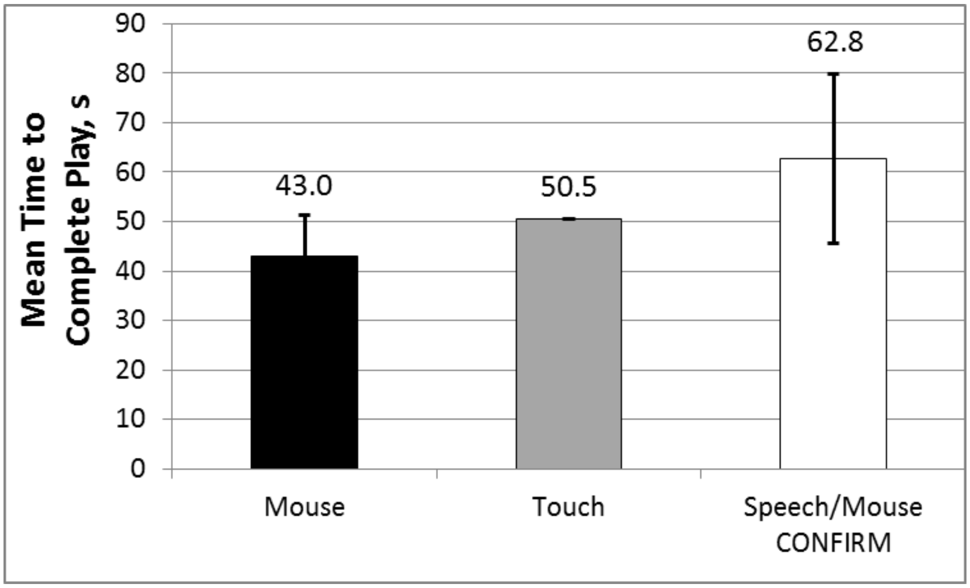

Figure 25. Time to Complete a Play Call by Modality. (Error Bars are the Standard Errors of the Means)

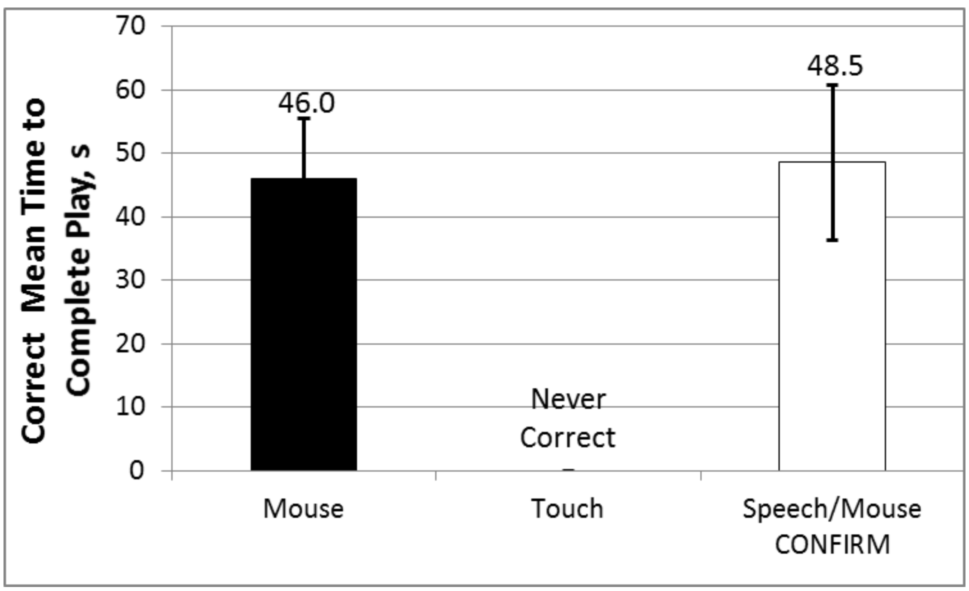

Figure 26. Time to Complete a Correct Play Call by Modality. (Error Bars are the Standard Errors of the Means)

Mission Debrief

Both UAV operators and security force personnel had positive comments about IMPACT's real world utility. For example, one UAV operator discussed how IMPACT could provide a Combined Air Operations Center (CAOC) commander with an excellent overview of the battlespace, while one security force specialist felt that IMPACT's capabilities could reduce the number of manned patrols and watch towers needed during base defense operations. Participants also suggested that the scenario could be improved by increasing the mission length, adding important mission considerations like fuel (UxVs had unlimited fuel), airspace deconfliction, and communication range as well as by adding more complex intruder events like mortar launches, gate runners, vehicle-borne improvised explosive devices, and base perimeter breaches. Security force personnel provided descriptions of base defense tasks like random anti-terror measures that should be incorporated in future scenarios (e.g., randomly searching a section of the base's perimeter fence for signs of tampering), cordons (e.g., blocking off the area surrounding a suspicious vehicle), and blockades (e.g., surrounding a suspicious watercraft) as well as constraints (e.g., UGVs should always have at least 50% fuel so they can remain effective in the case of an unexpected intruder).

5. DISCUSSION

The goal of the IMPACT project is to design a system that enables one operator to efficiently manage multiple heterogeneous UxVs in dynamic operating environments. To this end, multiple autonomous components are being developed. CCAs rapidly calculate optimal vehicle routes based on situational constraints. This involved making advancements in terms of developing motion models for ground and surface vehicles and trajectory planning for new plays. Intelligent agents recommend plans based on situational factors as well as in response to operator requests. During this reporting period, knowledge of mission-related activities was captured in the ontology and reasoning was enhanced to accommodate actions that are contextually appropriate. The Rainbow autonomics framework monitors the ongoing situation and alerts the operator to errors which involved modeling plans from play information and the generation of gauges from play specifications to monitor performance. These autonomous tools, along with advances in novel HAI, provide the operator with the ability to remain agile in demanding simulated base defense missions. Another significant accomplishment was the integration of these technologies into a high-fidelity simulation featuring the Fusion framework and this required developing a message standard to bridge CCA, IAs, and the Rainbow monitoring service. Besides these development efforts that improved the IMPACT simulation, other related research efforts were conducted to develop a model of an operator's workload as well as determining factors that influence the transparency of IA's reasoning to the operator. Publications related to the advancements in automation are provided after the references.

The reported study examined the usability of the IMPACT Spiral 1 system. Even though the Spiral 1 feature set was a subset of the envisioned Spiral 2 IMPACT system, five out of six participants strongly agreed that IMPACT has the potential to be a great aid in future UxV operations. Additionally, all participants agreed that IMPACT has the potential to improve operator situation awareness and reduce operator workload. Participants rated both the overall IMPACT system and system subcomponents including play calling, autonomy, feedback, and testbed positively.

> *"For force protection this would be spectacular."* – UAV Operator
>
> *"It's exactly what you need. They're great tools."* – Security Force Specialist

This study also examined the modality that participants used when calling plays. Participants overwhelmingly used the mouse compared to the touchscreen or speech recognition, and were faster and more accurate with the mouse. Several factors may have contributed to these results. Multiple participants had difficulties with the touchscreen registering their inputs. For example, it would often take a participant multiple attempts of touching a play icon before the system responded. In fact, some participants suggested in their comments that if the touchscreen had worked better they would have been more likely to use it. Several participants spoke favorably of speech in their comments, especially the security force

> *"Touchscreen could be extremely intuitive and quick if implemented correctly."* – UAV Operator

personnel, who mentioned that the speech commands were very similar to the dispatch calls they make during security force operations. However, this preference was not reflected in performance, as participants used the mouse/keyboard to call plays more than the speech. Several participants commented that they weren't completely familiar with the speech vocabulary, suggesting that training may not have been sufficient. In the end, participants may have chosen to use mouse/keyboard due to its reliability; clicking a play icon with the mouse consistently resulted in the desired action, while touching a play icon or issuing a voice command often failed to support task completion.

Limitations

The biggest limitation of this study was the lack of objective measures; though participants provided positive subjective feedback in regards to IMPACT, the extent to which IMPACT improves operator performance is yet to be determined. The mission duration was also short, limiting the opportunity to investigate the degree to which operators could seamlessly transition between plays. Additional limitations included the small number of participants and the length of time (only ~3.25 hours) participants were exposed to IMPACT. Operators with greater experience with IMPACT may have been more comfortable using the touchscreen and/or speech recognition.

Towards Spiral 2

Participant feedback informed and improved IMPACT's Spiral 2 development. For example, participants expressed a desire to directly manipulate UxVs and call plays from the map, features that will be implemented in Spiral 2. Participant concern about map clutter led to plans for a decluttering tool that provides smart automatic decluttering (e.g., dimming all unrelated UxVs when calling a play) as well as manual controls for the operator to declutter situationally relevant details like route waypoints and route labels. Finally, participant suggestions of improving the details panel led to the development of play widgets that allow an operator to graphically manipulate loiter patterns (as opposed to changing textbox values). As shown in Figure 26, users can change loiter direction by clicking the arrow and can change loiter size by clicking and dragging the loiter pattern.

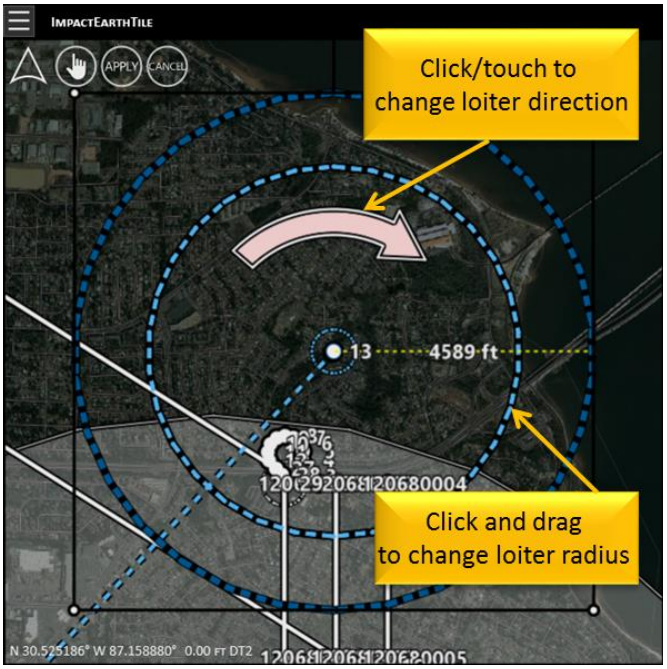

Figure 27. Loiter Pattern Widget that enables an operator to quickly change loiter parameters directly from the sandbox map, such as loiter direction, radius, and position.

Participant feedback also generated research questions that led to additional empirical studies. For example, several participants felt the Play Creator tile could be improved by organizing play icons by vehicle type rather than by play type. A study was conducted examining the effects of icon organization and the results supported participant opinions; icons organized by vehicle type may improve an operator's ability to locate the correct icon (Mersch, Behymer, Calhoun, Ruff, & Dewey, 2016). Additionally, participants liked teaming with the IA, but expressed a desire to understand how the IA reasoned. To support this, several plan comparison tools were developed to help operators compare IA generated plans, with a tool using a plan comparison plot showing promise (Behymer, Mersch, Ruff, Calhoun, & Spriggs, 2015).

In Spiral 2, IMPACT capabilities will be significantly enhanced and improved. Speech recognition will be more accurate and the list of commands will be expanded. Additionally, a higher touch resolution touchscreen will be added to improve the IMPACT's touch capability. New plays that use multiple UxVs in a highly coordinated fashion will be developed, such as: communication relays, blockades, cordons, and escorts. Improvements to the autonomous components will include making CCA planned routes editable, allowing operators to communicate priorities to the IA to improve its recommendations, and providing more status monitoring capabilities via the Rainbow Autonomics framework. This enhanced system will be vital as the difficulty of the mission will be increased in Spiral 2. The capabilities, varieties, and number of UxVs under the operator's control will also be increased, and operators will be responsible for handing vehicle failures, environmental events, and base intruders.

In order to assess the effectiveness of IMPACT's autonomous capabilities, the Spiral 2 iteration of IMPACT will be compared to a baseline system without IAs, Rainbow, and associated HAI components. For example, in the baseline conditions participants will utilize capabilities including basic “drag and drop” movement and assignment of assets to set patterns (e.g., loiter), vector-directed control, and waypoint-directed plans created by the operator via waypoint manipulation or with the assistance of a CCA algorithm rather than call plays. The IMPACT system will have the baseline capabilities with the addition of an expanded CCA to assist with route planning, IAs to support plan recommendations and monitoring mission goals, and the Rainbow autonomics framework to support error detection and improved plan recommendations. Operator performance and overall mission effectiveness is expected to be significantly better with IMPACT, especially for more complex mission conditions, given the flexibility and agility it affords in conducting the mission.

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LIST OF ACRONYMS

AFRL 711HPW/RHCI	Supervisory Control and Cognition Branch, Warfighter Interface Division, Air Force Research Laboratory, Airman Systems Directorate, 711th Human Performance Wing
AFSC	Air Force Specialty Code
AMASE	AVTAS Multi-Agent Simulation Environment
ARPI	Autonomy Research Pilot Initiative
ASD R&E	Assistant Secretary of Defense for Research and Engineering
AVTAS	Aerospace Vehicle Technology Assessment and Simulation
CAOC	Combined Air Operations Center
CCA	Cooperative Control Algorithm
CTA	Cognitive Task Analysis
ETE	Estimated Time Enroute
HAI	Human Autonomy Interface
HUMINT	Human Intelligence
IMPACT	Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies
IA	Intelligent Agent
IR	Infrared
MDARS	Mobile Detection Assessment and Response System
ROZ	Restricted Operating Zone
SUS	System Usability Scale
UAV	Unmanned Air Vehicle
UGV	Unmanned Ground Vehicle
USV	Unmanned Surface Vehicle
UxV	Unmanned Vehicle
WPAFB	Wright-Patterson Air Force Base
XMPP	Extensible Messaging and Presence Protocol

APPENDIX A – Background Questionnaire

Intelligent Multi-UxV Planner with Adaptive Collaborative/Control Technologies (IMPACT) – Initial Evaluation

ID#_____

BACKGROUND QUESTIONNAIRE:

Experience with Unmanned Vehicle Operations (ball park estimates):

Vehicle Name	Non-Combat Flight Hrs.	Combat Flight Hrs.

Other Previous Flight Experience (Most recent first):

Aircraft	Ball park number of flight hours

Experience with Security Forces and/or Base Defense (ball park estimates):

Job/Deployment	Length

APPENDIX B – Overall System Questionnaire

IMPACT DEBRIEFING QUESTIONNAIRE

We would like to first capture your general impressions of the overall IMPACT concept for supporting future scenarios involving multiple types of highly autonomous remotely piloted vehicles (UxVs). The IMPACT concept includes all the display formats, symbology, control methods and ability to call plays verbally and manually, as well as tailor plan parameters.

1) Please indicate which response best matches your opinion of the POTENTIAL VALUE of the IMPACT concept for future UxVs operations:

Negative Impact ☐	No Aid ☐	☐	☐	☐	☐ Great Aid	
	1	2	3	4	5	

2) Please indicate which response best matches your opinion of the ability of the IMPACT concept to aid your WORKLOAD for future UxVs operations:

Negative Impact ☐	No Aid ☐	☐	☐	☐	☐ Great Aid	
	1	2	3	4	5	

3) Please indicate which response best matches your opinion of the ability of the IMPACT concept to aid your SITUATION AWARENESS during future UxVs operations:

Negative Impact ☐	**No Aid** ☐	☐	☐	☐	☐	**Great Aid**
	1	**2**	**3**	**4**	**5**	

Next we would like to capture your general impression on how USABLE you found this first instantiation of IMPACT in general. This involves responses to a scale and open ended questions.

System Usability Scale
Page 1 of 2

Please answer the following questions by circling a single number from 1 (strongly disagree) to 5 (strongly agree).

	Strongly Disagree				Strongly Agree
1. I think that I would like to use this system frequently.	1	2	3	4	5
2. I found the system unnecessarily complex.	1	2	3	4	5
3. I thought the system was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5. I found the various functions in this system were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this system.	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8. I found the system very cumbersome to use.	1	2	3	4	5
9. I felt very confident using the system.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Please answer the following questions with your honest opinion, providing as much detail as possible:

11. What did you like most about the system?

System Usability Scale
Page 2 of 2

12. What did you like least about the system?

13. What was confusing about the system?

14. How would you improve the system?

APPENDIX C – Component Specific Questionnaires

FEEDBACK ON IMPACT FEATURES

Next we are going to have you consider specific features of the IMPACT concept, thinking you might have additional comments or suggestions that you haven't already raised. You may want use the IMPACT simulation or our handouts for reference in providing your feedback. For some features, we would also appreciate you providing a few ratings.

a. One key feature is the ability to direct the UxVs with HIGH-LEVEL AUTOMATED PLAYS. This involved several components listed below. Do you have any additional thoughts of what you liked or didn't like about any of these, or suggestions for improvement?

1. **Play Tile:** Tile with icons for default/pre-planned plays
2. **Work-flow tiles:** Expandable tiles to view/specify play details
3. **Preset Panel:** size, visibility, optimize, priority, sensor options; icons
4. **Steps to Call High-Level Plays:** verbal and/or manual commands
5. **Steps to Designate a Location:** voice, "hand tool", drop down menu
6. **Steps to Select/De-select Assets**
7. **Steps to Call up Alternative Plans from Autonomy**
8. **Steps to Tailor/Change Default Parameters:** change preset, add UxV, change loiter, move stare point, modify route, add sensor, etc.
9. **Steps to Tailor/Change Parameters of Plays in Progress**
10. **Approval Steps:** use of verbal command or checkmark selection to approve plan & initiate play

Please rate your view of the POTENTIAL VALUE of the ability to call HIGH-LEVEL AUTOMATED PLAYS for future UxVs operations:

Negative Impact ☐	No Aid ☐	☐	☐	☐	☐ Great Aid
	1	2	3	4	5

Comments:

Also use the scale below to indicate the USABILITY of the interface to call HIGH-LEVEL AUTOMATED PLAYS (the "system" in each row below) for future UxVs operations:

	Strongly Disagree				Strongly Agree
1. I thought the system was easy to use.	1	2	3	4	5
2. I found the various functions in this system were well integrated.	1	2	3	4	5
3. I thought there was too much inconsistency in this system.	1	2	3	4	5
4. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5

b. Advances in AUTONOMY also plays a key role in the IMPACT. Below are a few features to prompt additional feedback on. Do you have any additional thoughts of what you liked or didn't like about any of these, or suggestions for improvement?

1. **Route Planning:** time it takes to generate a plan, acceptability of plan, etc.
2. **Recommended Assets:** blue brackets on UxV symbols
3. **Suggested Plays:** prompt in feedback window, button options to ignore, view, or accept
4. **Quality Graph of Play's Progress:** sprocket pie slice size, threshold indicators, color warnings
5. **Suggested Plays/Actions:** messages in feedback bar

Please rate your view of the POTENTIAL VALUE of the role of AUTONOMY in IMPACT:

Negative Impact ☐	No Aid ☐	☐	☐	☐	☐	Great Aid
	1	2	3	4	5	

Comments:

Also use the scale below to indicate the USABILITY of AUTONOMY (the "system" in each row below) as illustrated in IMPACT for future UxVs operations:

	Strongly Disagree				Strongly Agree
1. I thought the system was easy to use.	1	2	3	4	5
2. I found the various functions in this system were well integrated.	1	2	3	4	5
3. I thought there was too much inconsistency in this system.	1	2	3	4	5
4. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5

c. Providing FEEDBACK OF STATUS was also a key feature in IMPACT. Do you have any additional thoughts of what you liked or didn't like about any of these, or suggestions for improvement?

1. **Table of Plays:** list of active plays & any warnings
2. **Mini Play Tile:** plus, line, square denoting point, line, area search & other shape coding
3. **Detailed Play Tile:** play icon, name, assets, quality sprocket, edit button
4. **Feedback on Quick Reaction Force state:** lightning bolt pixel tag
5. **Edit Mode:** feedback on Play Tiles & Workflow tiles
6. **Vehicle Type:** shape coding for air, ground, sea UxVs
7. **Detailed Vehicle Tile:** play icon, colors for play status & fuel, payload info, call sign
8. **Vehicles on Map:** shape coding & indicators on selection & warning status
9. **Routes on Map:** dashed=proposed, solid=active
10. **Caution/Warning Alerts:** play tile, vehicle tile, colors on vehicle icons, workflow tile

Please rate your view of the POTENTIAL VALUE of the role of FEEDBACK OF STATUS in IMPACT:

Negative Impact ☐	No Aid ☐	☐	☐	☐	☐ Great Aid
	1	2	3	4	5

Comments:

Also use the scale below to indicate the USABILITY of the FEEDBACK (the "system" in each row below) as illustrated in IMPACT for future UxVs operations:

	Strongly Disagree				Strongly Agree
1. I thought the system was easy to use.	1	2	3	4	5
2. I found the various functions in this system were well integrated.	1	2	3	4	5
3. I thought there was too much inconsistency in this system.	1	2	3	4	5
4. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5

d. Finally, the TESTBED is a key element to IMPACT. Do you have any additional thoughts of what you liked or didn't like about any of these, or suggestions for improvement?

1. **Tactical Situation Awareness Display:** interactive and dynamic map
2. **Color Coding:** all routes/UxVs on same play a unique color; unassigned UxVs gray
3. **"Selected" status:** white (operator) or blue (autonomy) brackets; indication of selected UxV on map and in UxV tile
4. **Left Side Display:** chat and status information
5. **Right Side Display:** payload sensor info
6. **Voice Commands:** headset, mic, feedback bar, vocabulary (including UxV type distinctions)
7. **Touch Displays:** sensitivity, reach envelop, feedback
8. **Mouse/Keyboard:** implementation of push-to-talk
9. **Moving/Managing tiles:** was it necessary to move tiles, do you have a preference on tile locations across the screens

Please rate your view of the POTENTIAL VALUE of the role of TESTBED in IMPACT:

Negative Impact ☐	**No Aid** ☐	☐	☐	☐	☐	**Great Aid**
	1	**2**	**3**	**4**	**5**	

Comments:

Also use the scale below to indicate the USABILITY of the TESTBED (the "system" in each row below) as illustrated in IMPACT for future UxVs operations:

	Strongly Disagree				**Strongly Agree**
1. I thought the system was easy to use.	**1**	**2**	**3**	**4**	**5**
2. I found the various functions in this system were well integrated.	**1**	**2**	**3**	**4**	**5**
3. I thought there was too much inconsistency in this system.	**1**	**2**	**3**	**4**	**5**
4. I would imagine that most people would learn to use this system very quickly.	**1**	**2**	**3**	**4**	**5**

APPENDIX D – Post-Mission Debrief Guide
Post-Mission Debrief Guide

Note: This portion of the post-mission debrief will be semi-structured. While all question categories will be covered, the specific questions may vary from interview to interview (e.g., base defense personnel will be asked different questions than UxV operators). The questions listed are provided as examples of the types of questions that may be asked.

1. Air Force Specialty Code (AFSC) related example questions
   a. How would you incorporate unmanned vehicles with these capabilities into base defense?
   b. What challenges do you envision for integrating unmanned vehicles into base defense operations?
   c. How do you think the ability to utilize different types of unmanned vehicles and associated advancements in autonomy will impact base defense operations?
   d. What challenges do you envision for managing multiple unmanned vehicles?

2. Scenario related example questions
   a. What was challenging about the scenario?
   b. How can we make the scenario more challenging?
   c. If you had unlimited time and funds to design a training scenario to train base defense personnel (or UxV operators) what would that scenario look like? How would you evaluate trainee performance?
   d. What mistakes would a novice base defense operator make in this scenario?
   e. Is scenario representation sufficient/adequate to assess new interface approach? How could the scenario be improved? What is missing from the scenario?
   f. To prioritize future developments, what other types of tasks and/or information feeds should be developed and integrated into the simulation?

3. IMPACT system related example questions
   a. How would this interface help you manage the challenge of managing multiple unmanned vehicles? How would it be inadequate?
   b. What interface features did you find most useful?
   c. What interface features did you find least useful?
   d. What interface features did you find confusing?
   e. Would you prefer the autonomy to recommend the course of action it thinks is best or to generate a set of alternatives you could select from?
   f. During the scenario we noticed you (e.g., only used voice commands instead of the other input modalities)? What made you (e.g., use voice)?