Cite as: Scott, S.D., Wan, J., Rico, A., Furusho, C., Cummings, M.L. (2007). Aiding Team Supervision in Command and Control Operations with Large-Screen Displays. In *Proceedings of HSIS 2007: ASNE Human Systems Integration Symposium*, March 19-21, 2007, Annapolis, MD, USA.

Stacey D. Scott, Jordan Wan, Alma Rico, Carina Furusho, M.L. Cummings

Aiding Team Supervision in Command and Control Operations with Large-Screen Displays

ABSTRACT

Large-screen wall displays are becoming a common fixture in command and control environments. However, few guidelines are available to help designers determine what data or which interface mechanisms are most suitable for these information displays. Building on anecdotal evidence suggesting that these displays are commonly used by commanding officers to gather mission status information, this research aims to explore the use of large-screen displays to support team supervision in time-critical command and control operations. In particular, the goal of this research is to investigate new information visualization and data fusion methods to help provide situation and activity awareness to mission commanders overseeing teams of unmanned vehicle operations engaged in intelligence, surveillance, and reconnaissance (ISR) missions. The paper describes a cognitive task analysis (CTA) of a representative team ISR mission to identify functional and information requirements for the large-screen information displays that would be used by the mission commander in such ISR missions. The results of the CTA led to the development of two large-screen mission commander displays, as well as a software simulation environment designed to evaluate the effectiveness of the display concepts incorporated into these displays.

INTRODUCTION

Large-screen displays are becoming an integral part of command and control team environments. For instance, the battle management centers for future naval ships will include several wall-mounted large-screen displays for providing mission and ship related information. It is generally agreed that such large displays, often called situation displays, should provide information which enables the operations team to maintain awareness of the overall battlefield situation, otherwise known as the 'big picture' (Dominguez, 2006; Dudfield et al., 2001; Jenkin, 2004; Pester-DeWan et al., 2003; Roth et al., 1998). However, few guidelines currently exist to help determine precisely what information sources should be shown on these large displays, or what interface techniques should be used to provide this information in an appropriate format. Also, it is not well understood how different command and control personnel use these large displays. Anecdotal evidence suggests that these displays are commonly used by commanding officers to gather mission status information (Dudfield et al., 2001).

Building on this anecdotal evidence, the goal of this research is to explore the potential use of large-screen displays to support team supervision in time-critical command and control operations. In particular, this project is focused on supporting commanders who oversee missions involving teams of operators interacting with semi-autonomous unmanned aerial vehicles (UAVs) to perform ISR activities in support of a time-sensitive targeting mission, as might be performed by future littoral combat ship (LCS) or broad area maritime surveillance (BAMS) operations teams.

A cognitive task analysis (CTA) was performed on a representative team ISR mission to identify functional and information requirements based on the team supervisor's role in the collaborative activity and the supervisory decisions required throughout the mission. The results of the CTA informed the design of two large-screen, interactive situation displays: a situation map display and a mission status display.

To set the context for the CTA and these large-screen displays, the following section describes the representative team ISR task scenario. The CTA methodology is then described, along with a summary of the resulting functional and information requirements. Finally, the paper presents the large-screen mission commander displays and discusses how they satisfy the generated requirements.

REPRESENTIVE TEAM ISR TASK

In order to better understand how to develop display technologies that assist ISR operations teams, a representative ISR team task scenario was developed. The task scenario involves a team of operators working together to secure a large geographic area (the team's area of interest (AOI)) to ensure the safe passage of an important political convoy that will be traveling through the area in the near future. During the task, the team will be required to surveil the area for potential threats. Once hostile targets have been identified, the team must coordinate with an external strike team to engage these hostile contacts before they are within weapons range of the convoy. The team will be required to monitor incoming intelligence reports in order to extract information relating to their AOI and potentially communicate with other teams as necessary to clarify intelligence reports.

In order to secure the AOI, the team will be required to utilize a number of semi-autonomous unmanned aerial vehicles (UAVs). Various team members will be required to monitor the progress of these UAVs as they provide surveillance of the large AOI and to reroute the UAVs from their original surveillance course, as necessary to secure the area. The team may also be required to coordinate with other teams to utilize assets outside of their immediate control to help secure the AOI.

The UAV operations team consists of three UAV operators, each responsible for controlling multiple UAVs, and one mission commander overseeing the team's mission progress. The UAV operators are responsible for supervising the progress of several UAVs surveilling the AOI, confirming potential targets identified by the UAVs' onboard automatic target recognition (ATR) systems, and coordinating with a strike team to destroy confirmed targets. This task scenario assumes advanced onboard ATR capability, as well as the use of a distributed ISR Cell that would liaise with this UAV team for any necessary detailed image analysis.

The mission commander is responsible for ensuring the safety of the convoy and for managing the workload of the UAV operators on his or her team throughout the mission.

To achieve these mission objectives, the mission commander can make several types of strategic decisions, which include requesting the convoy hold its current position if its intended path is not deemed safe for passage, requesting supplementary surveillance data from a nearby joint surveillance and target attack radar system (JSTARS), and re-tasking of one of the team's UAV assets to a different sub-AOI (requiring the handoff of the UAV asset between operators).

While there are many collaborative components to this task scenario, the current phase of the project is focused on the decision-making and performance of the mission commander (i.e. the team supervisor) managing the overall tasking of the UAV operations team.

COGNITIVE TASK ANALYSIS OF THE MISSION COMMANDER

Since the task scenario describes a mission that involves anticipated UAV platforms and capabilities, it represents a futuristic military task scenario. Thus, a Hybrid Cognitive Task Analysis (CTA) (Nehme et al., 2006), an analysis method designed specifically to assist the development of revolutionary systems, was conducted to generate the design requirements for the team supervisory decision support displays. The traditional CTA approach requires subject matter experts, documentation, and existing system implementations to derive design requirements, resources unavailable in futuristic systems with no predecessors. The Hybrid CTA takes these constraints into account and presents a structural process to aid in the generation of design requirements.

The Hybrid CTA compensates for the lack of subject matter experts, previous implementations and documentation by modifying the task decomposition phase of a traditional CTA into a four-step process:

1. generating a scenario task overview,
2. generating an event flow diagram,
3. generating situation awareness requirements, and
4. creating decision ladders for critical decisions.

The process first establishes a high-level mission outline and ultimately allows the analyst to extract functional and information requirements from the decision ladders.

A scenario task overview serves as the foundation of the Hybrid CTA (henceforth referred to as the CTA). For this research, the task scenario described above will serve as the scenario task overview. Moreover, for this particular phase of the project, only the mission commander's role in the task scenario is considered throughout the CTA. The results of the CTA are summarized below (for full details see (Scott et al., 2006)).

Scenario Task Overview

In this step of the CTA, the mission goal is first established and then divided into phases based on changes in operator tasking. A hierarchy is created by creating sub-goals within each phase and then detailing the subtasks for each of these sub-goals, finally leading to individual subtasks. Three main phases were identified: mission planning, mission execution, and mission recovery. Since this project is focused on developing support for the mission execution phase (which may involve some mission re-planning), the sub-goals and subtasks for this phase are included in a scenario task overview table (see Figure 1 for an excerpt of this tables). Any assumptions related to mission planning and recovery tasks are also listed in the scenario task overview.

Event Flow Diagram

Next, an event flow diagram is constructed to demonstrate the dependency between task and subtask events identified in the scenario task overview. The diagram helps articulate the temporal constraints between these events. Figure 2 depicts the event flow diagram that was constructed from the scenario task overview. The diagram provides the details of the mission execution events, along with the assumed inputs from the mission planning phase. The potential events leading to mission recovery are also shown.

Diamonds depict decisions, hexagons represent loops, and rectangles depict processes involving human-computer interaction. Each decision results in a yes or no answer, which leads to another event. Gray diamonds indicate decisions deemed complex enough to expand into decision ladders. Decision ladders emulate the cognitive and human-computer interaction activities involved with that decision.

For example, the main mission execution decision (D1), establishes whether the convoy has exited the geographical region. If the convoy has exited the region, the mission proceeds to the mission recovery phase, otherwise the mission commander enters a monitor team status loop (L1).

<table>
<tr><td>Mission Planning</td><td colspan="2">Issues to be resolved in this phase:
• Each UAV will have initial routes planned
• Each operator will have a pre-defined area under his/her responsibility</td><td>Helpful information for resolving these issues:
• Time average target destruction will take based on: UAV surveillance speed; engagement time (operator target confirmation time, communication time with strike team, strike team schedule timing)
• JSTARS and strike team availability
• Expected convoy arrival time, ground speed, path</td></tr>
<tr><td rowspan="4">Mission Execution: Basic phases/ events</td><td>Phase goals</td><td colspan="2">Phase Breakdown</td></tr>
<tr><td>ISR</td><td colspan="2">• UAVOP monitors sub-AOI, while the UAVs search for potential threats
• JSTARS detect additional targets and communicate to the UAV team when requested.</td></tr>
<tr><td>Target detection</td><td colspan="2">• UAV's onboard automatic target recognition (ATR) sends a potential target alert to the controlling UAVOP
• UAVOP examines ATR imagery to confirm or refute target identification
• If target confirmed, UAVOP submits target details to strike team for strike scheduling</td></tr>
<tr><td>Target strike</td><td colspan="2">• When the strike team is scheduled to strike a target, it engages the target of interest
• Strike team notifies UAV team when target is destroyed</td></tr>
</table>

Figure 1. Excerpt from the scenario task overview table.

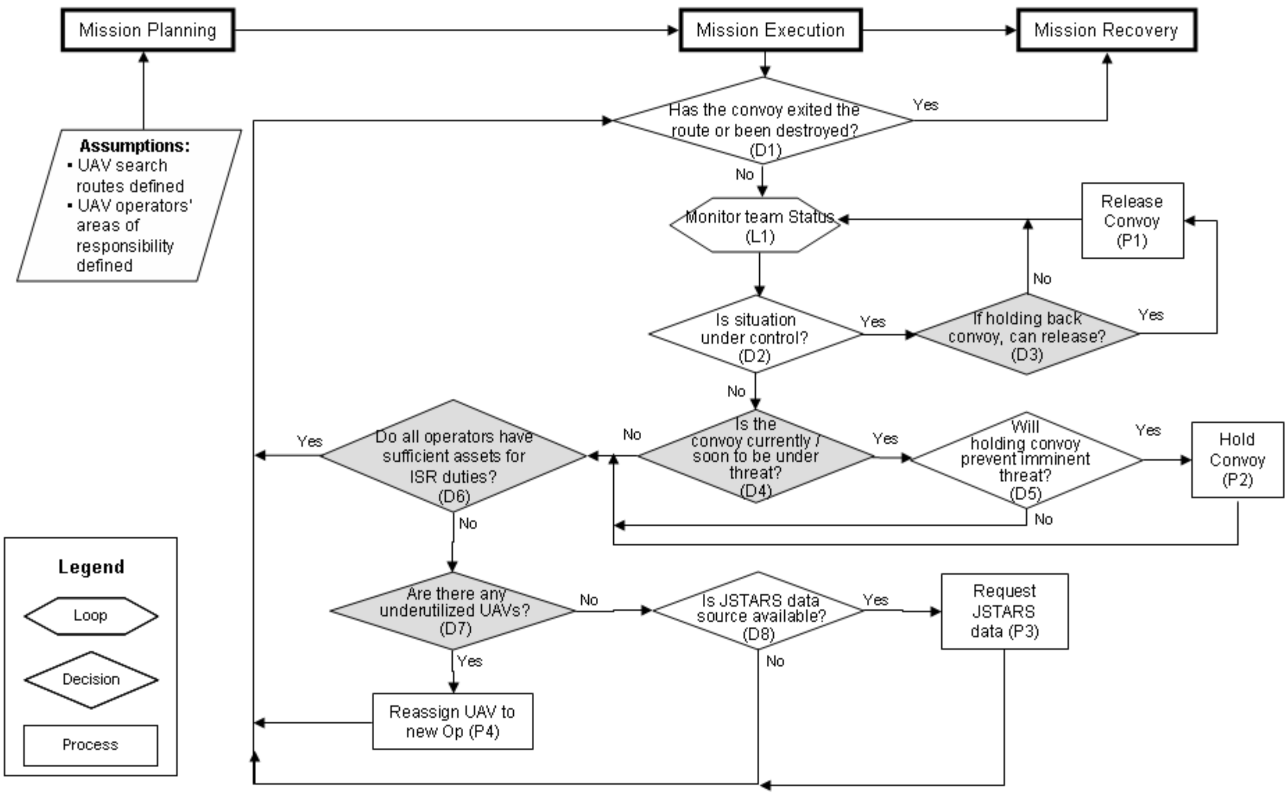

Figure 2. Event Flow Diagram including loops, decisions, and human-computer interactions by mission commander.

Situation Awareness Requirements

The third step in the CTA involves generating a list of situation awareness (SA) requirements based on the temporal constraints of the event flow diagram for each sub-phase and subtask in the scenario task overview. Each requirement is divided into the three levels: perception, comprehension, and projection, which represent the essential mental processing needed to gain situation awareness (Endsley, 1995).

Figure 3 shows an excerpt from the SA requirements table for the events that may occur during the mission execution phase of the task. The SA requirements listed in this table focus on the information that the UAV team, and in particular the mission commander, may need to perceive and comprehend the current state of the UAV operators' activities, the convoy's safety, and the UAV team's overall mission performance. The SA table also identifies information the mission commander may need to predict the future state of these issues throughout the tasks within each mission event (as listed in the scenario task overview).

Decision Ladders and Display Requirements

Lastly, the CTA attempts to elucidate the mission commander's thought process by generating decision-ladders for critical decision points within the task scenario. Decision ladders map out a person's decision-making process by articulating what knowledge is needed for critical decisions in the event flow diagram. Each decision ladder constructs a visual outline of knowledge and information-processing states leading up to a decision (Rasmussen, 1983). These decision ladders are then augmented with addition information that describes what information should be provided by a decision support system in order to support each of the knowledge and information processing states.

Four main decisions (D3, D4, D6 and D7) from the event flow diagram were determined to be sufficiently complex to warrant the construction of detailed decision ladders and, ultimately, the identification of display requirements for these complex decisions. Figure 4 illustrates the resulting decision ladder for decision D4 (Is the convoy currently or soon to be under threat?). In Figure 4, the

Phases/Events	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
ISR	-All agents position information (UAVs, convoy) & target positions on geospatial map -Geo-spatial boundaries -Indication of which UAVOP are controlling which UAVs -Communication status with intelligence assets and strike team -Current workload of each UAVOP	-Error/alert message clarification -Vehicle's limitations (on demand) - UAVOP status and performance - Each operator number of targets and their status -Visual indication of operator workload in relation to UAV tasking and convoy safety	-Estimated convoy paths and progress time -Estimated position/type of each target and range to convoy -Uncertainties -Currently planned UAV routes -Estimate of UAV ISR coverage in relation to convoy progress -Potential missed ISR coverage along convoy path -Prediction of vehicle's health and status -Prediction of convoy's health and safety status -Prediction of operator workload
Target detection / confirmation	-Alert of target detection from UAV - Indicate which UAV is detecting target -Geo-spatial boundaries -visual indication of comms link to intelligence assets and strike team	-Error/alert message clarification -Target information from all intelligence assets	-Target type/range (short, medium, long) -Estimated distance range of target to convoy -Availability of strike team to schedule target strike -Schedule of target strikes
Target Strike	- Visual feedback for engagement confirmation	-Confirmation from Strike Team of target status - Confirmation of destroyed targets	-Predicted strike time -Estimated distance range to convoy of each target -Uncertainty of strike

Figure 3. Excerpt from the SA requirements table.

left-side of the decision ladder represents the information gathering and analysis aspects of the decision-making process, while the right-hand side shows the actions necessary to execute a decision.

The decision ladder depicts the states of knowledge in ovals and information-processing and human-computer (or human-human) interaction activities in rectangles. The decision making process begins with an activation event. The corresponding display requirements for relevant states in a decision-ladder are modeled in blue callout figures beside the corresponding states and activities.

Summary of Requirements Generated from the CTA

The CTA produced a wide variety of information requirements for supporting the mission commander during the task scenario. These requirements can be broadly categorized as requirements for providing: geospatial information, temporal information, health and status information, operator workload and tasking information, and alert and feedback information. These requirements are summarized in Table 1, grouped by these broad categories. For each requirement, Table 1 also indicates whether it originated from the analysis of the situation awareness requirements (SA), from the display requirements detailed in the decision ladders (Display), or from both (SA & Display).

The results of the CTA highlighted the importance of the mission commander staying apprised of the current and expected status of team members' task activities and their real-time progress towards meeting the mission goals. To address these issues, design concepts for providing *activity awareness* – a design approach focused on improving planning and coordination in teamwork through intelligent sharing of group activity information (Carroll et al., 2003; Carroll et al., 2006) – were incorporated in the design of the large-screen displays.

These concepts, along with the information requirements in Table 1, informed the design of two large-screen, interactive displays:

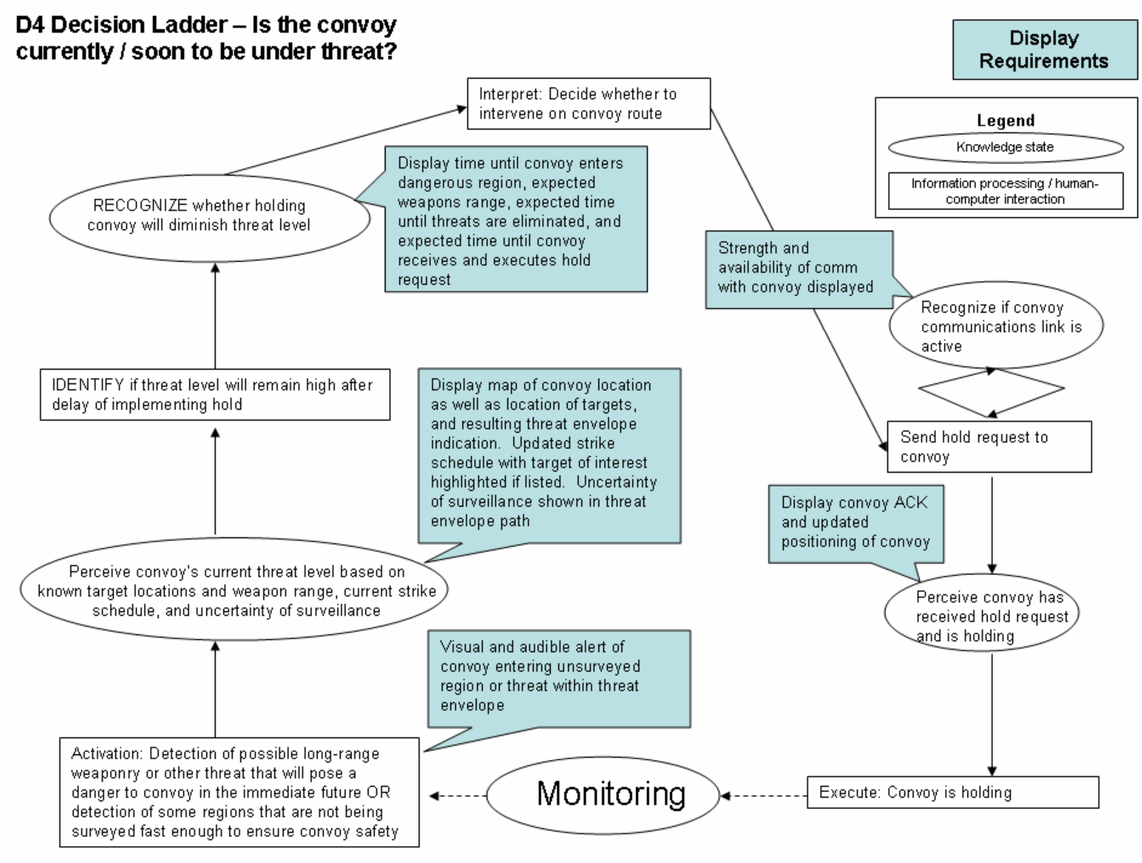

Figure 4. Decision ladder (augmented by display requirements) leading to holding of the convoy.

- a **situation map display** that visualizes positional information of relevant contacts and assets in a geographical context, and
- a **mission status display** that visualizes current and expected mission status information, including surveillance progress of each UAV operator, communication links to external resources, and scheduled strikes on known targets.

DISPLAY DESIGNS

The following sections detail the interface designs of the mission commander displays.

Situation Map Display

The main purpose of the Situation Map Display, shown in Figure 5, is to provide an up-to-date view of the main mission assets (e.g., convoy, UAVs, targets) in the context of the UAV team's area of interest, satisfying the geospatial information requirements generated by the CTA. The symbology used on this display is primarily based on standard military display symbology from MIL-STD-2525B (DOD, 1999), modified to satisfy the information requirements generated by the CTA for our futuristic task environment. System users, whether or not they are military personnel, will receive training to familiar themselves with this symbology as part of any future system testing.

In particular, the map symbology is designed to dynamically change through the mission to enhance the mission commander's awareness of possible threat and operator performance issues. For example, areas of the map which have not yet been surveilled are indicated by a semi-transparent black overlay. When a UAV surveils an area, its overlay is cleared. Thus, the current surveillance progress across the UAV team is indicated by the relative amount of clear and black areas in each operator's AOI. Ideally, these areas would fade back to black as time passes and the surveillance data ages (Bisantz et al., 2006).

Table 1. Summary of information requirements generated by the CTA.

Type	Requirement Description	Source
Geospatial Information	Display UAVs' current and future positions and paths	SA & Display
	Display current position of convoy and expected convoy path/progress	SA & Display
	Display expected weapons range	Display
	Estimated distance of convoy to potential / known threats	SA
	Display geospatial map showing all UAVs, convoy, targets, and known path information	SA & Display
	For each operator, indicate on map geospatial boundaries, currently unsurveilled areas, and which UAVs they are controlling	SA
	Indicate potentially missed surveillance areas, especially in range of convoy's expected path	SA
Temporal Information	Display expected UAV surveillance times for each operator	Display
	Schedule showing expected time of strike team destroying identified targets and basic information on each target (e.g., ID and type/range)	SA & Display
	Display uncertainty of target strikes	SA
	Estimated time until UAVs surveil the AOI, for each operator, in relation to convoy's progress	SA & Display
	Estimated convoy progress time	SA
	Estimated time until convoy will be within weapons range of unsurveilled areas	SA & Display
	Estimated time until convoy will be within range of any known targets	SA & Display
Health & Status Information	Current and expected communication connections to all external contacts	SA & Display
	Display strength of communication links	Display
	Convoy's current and expected health and safety status	SA
	Convoy's current and expected threat level based on distance to potential or known threats	Display
	UAV current and predicted health and status	SA
	UAV vehicle limitations on demand & when predicted to exceed safe operation	SA
	Target information from all intelligence assets	SA
	Target type/range (short, medium, long)	SA
	For each operator, number of targets and status of targets	SA
	Availability of strike team to schedule target strike	SA
	Availability of JSTARS	SA
	During target detection, indicate which UAV is detecting targets	SA
	Visually indicate when convoy is holding	Display
Operator Workload & Tasking Performance Information	Display UAV operators' status and performance	SA
	Display current and predicted workload of each UAV operator in relation to UAV tasking and convoy safety, and convoy's current and expected location	SA & Display
	Automated overall summary of current and expected future surveillance performance	Display
	Targets and status of each operator AOI	SA
	View operators' expected performance until expected time to get possible assistance.	Display
	Display each operator's current UAV assets	SA & Display
	Display current and future state of operator	Display
Alerts & Feedback Information	Display any intelligence about a target that attacks a UAV	SA
	Display acknowledgements of convoy holding / resuming progress	Display
	Display alert of convoy entering unsurveyed region or threat within threat envelope	Display
	Visual alert of target detection from UAV	SA
	Visual feedback / confirmation from strike team of target engagement confirmation	SA
	Visual alert of convoy approaching range of known target and unsurveilled areas	SA
	Visual alert when communications link is lost or regained to external contacts	SA
	Visual indication of UAV attack	SA
	Error / alert message clarification	SA
	Probabilities of convoy being attacked from particular weapons distance or target type	SA

Cite as: Scott, S.D., Wan, J., Rico, A., Furusho, C., Cummings, M.L. (2007). Aiding Team Supervision in Command and Control Operations with Large-Screen Displays. In *Proceedings of HSIS 2007: ASNE Human Systems Integration Symposium*, March 19-21, 2007, Annapolis, MD, USA.

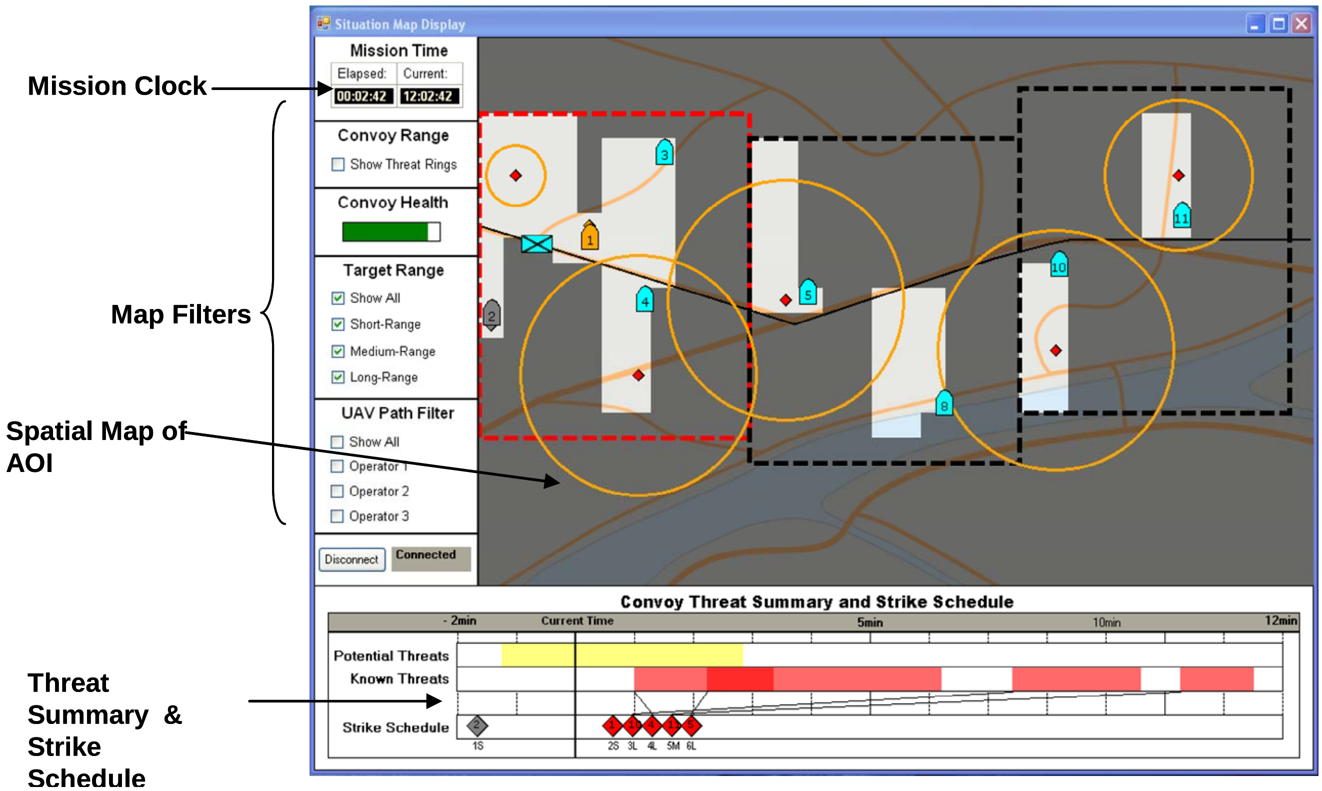

Figure 5. Situation Map Display.

When an operator is in the process of confirming a possible target detected by a UAV's onboard automatic target recognition (ATR) system, an orange target symbol is displayed on the map in the location of the detected target and the UAV that detected the target is displayed as orange. When the operator has finished confirming the target, the UAV returns to its nominal blue color and the target is displayed as red, indicating a known threat.

Some changes to the map symbology are designed to correspond to critical information also displayed on the second display, the Mission Status Display, in order to inform the mission commander of a critical status situation and to direct attention to the Mission Status Display for further information on the situation.

For example, the color of the AOI boundaries changes depending on operator performance, which is tracked and displayed in more detail on the Mission Status Display. A black boundary indicates the corresponding operator is expected to meet their ISR responsibilities. In particular, the operators are predicted to surveil areas in their AOI that are within weapons range of the convoy in the near future. When an operator begins to fall behind on surveillance and is not expected to surveil all areas within weapons range of the convoy, the boundary for that operator's AOI changes to yellow. If an operator's performance is expected to reach a critically low point, their AOI boundary will change to red. In this task, critically low performance indicates that an operator's has significantly fallen behind schedule in checking areas directly along the route of the convoy, perhaps due to UAV losses.

These dynamic changes to the map symbology are designed to help satisfy the health and status information requirements generated by the CTA.

The Situation Map Display also provides various view filters to enable the mission commander to show or hide extra display information, as needed during the mission. For example, weapons range rings can be shown around identified targets. These rings indicate the convoy's relative distance to threats in the area.

In order to satisfy the temporal information requirements related to the current and expected

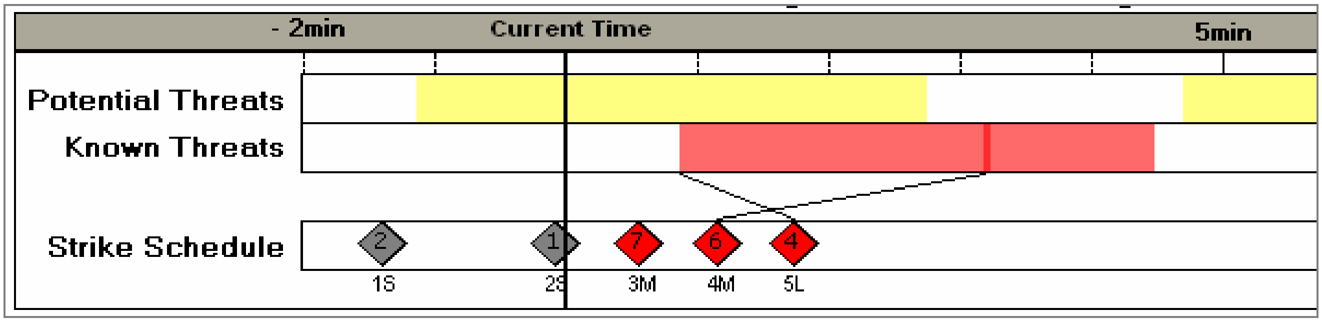

Figure 6. Strike schedule example: Threat 4M is scheduled to be destroyed 2 minutes *before* the convoy will be within its weapons range. Threat 5L is scheduled to be destroyed 1 minute *after* the convoy will be within its weapons range. Threat 3M is far enough away from the convoy's route that the convoy is not expected to pass within its weapons range, thus no corresponding 'threat window' is shown.

safety level of the convoy, an up-to-date Threat Summary timeline is provided at the bottom of the Situation Map Display (see Figure 6). This timeline indicates when the convoy is or is expected to be in range of any unsurveilled areas (i.e., a potential threat, shown as a yellow time window) or in range of a known threat (shown as a red time window). These time windows will be referred to as threat envelope, that is, durations of time in which the convoy will be in potential or known threat situations.

The timeline also shows the up-to-date target strike schedule in the context of the current and expected convoy threats. Known threats are shown as red diamonds in the last row of the timeline. The position of a known threat on the timeline indicates the scheduled time when it will be destroyed by the external strike team. If the convoy is or is expected to be within weapons range of a known threat, a black line is displayed between the target's symbol in the strike schedule and the beginning of its corresponding threat envelope in the row above.

Since humans are adept at perceiving differences in line angles (Ware, 2000), this connector line creates an emergent feature to help the mission commander identify off-nominal situations when a threat strike will not happen before the convoy will be within its weapons range. For example, when the mission commander sees a threat connector line at a vertical angle or sloping downwards to the right (e.g., the strike will be later than the convoy's arrival within the threat's weapons range), they should take action to delay the convoy and let the strike team destroy the threat before the convoy is allowed to continue.

Mission Status Display

The Mission Status Display shows various types of information designed to provide the mission commander current and expected status of the UAV operators' task performance, the convoy's safety level, and the UAV team's communication connections to remote contacts (see Figure 7). The results of the CTA highlighted the importance of supporting the mission commander's analysis of the ongoing temporal relationships between the UAV team's activities and the convoy's safety; thus, much of the status information presented on this display is provided in the form of timelines and time graphs that show the current situation, along with the recent history and the expected future status of mission related data.

In particular, the Mission Status Display contains a Convoy Threat Summary timeline (mirrored on the Situation Map Display as described above), Operator Performance time graphs, and Potential Convoy Threat Summary timelines. The Potential Convoy Threat Summary timelines provide a timeline for each operator region (AOI) that shows the periods of time when the convoy is or is expected to be within short, medium, or long range weapons range of any unsurveilled areas, due to UAV surveillance delays or UAV losses. Whenever the convoy is or is expected to be within range of a medium or short potential threat within a particular operator region, the alert to the right of the corresponding timeline

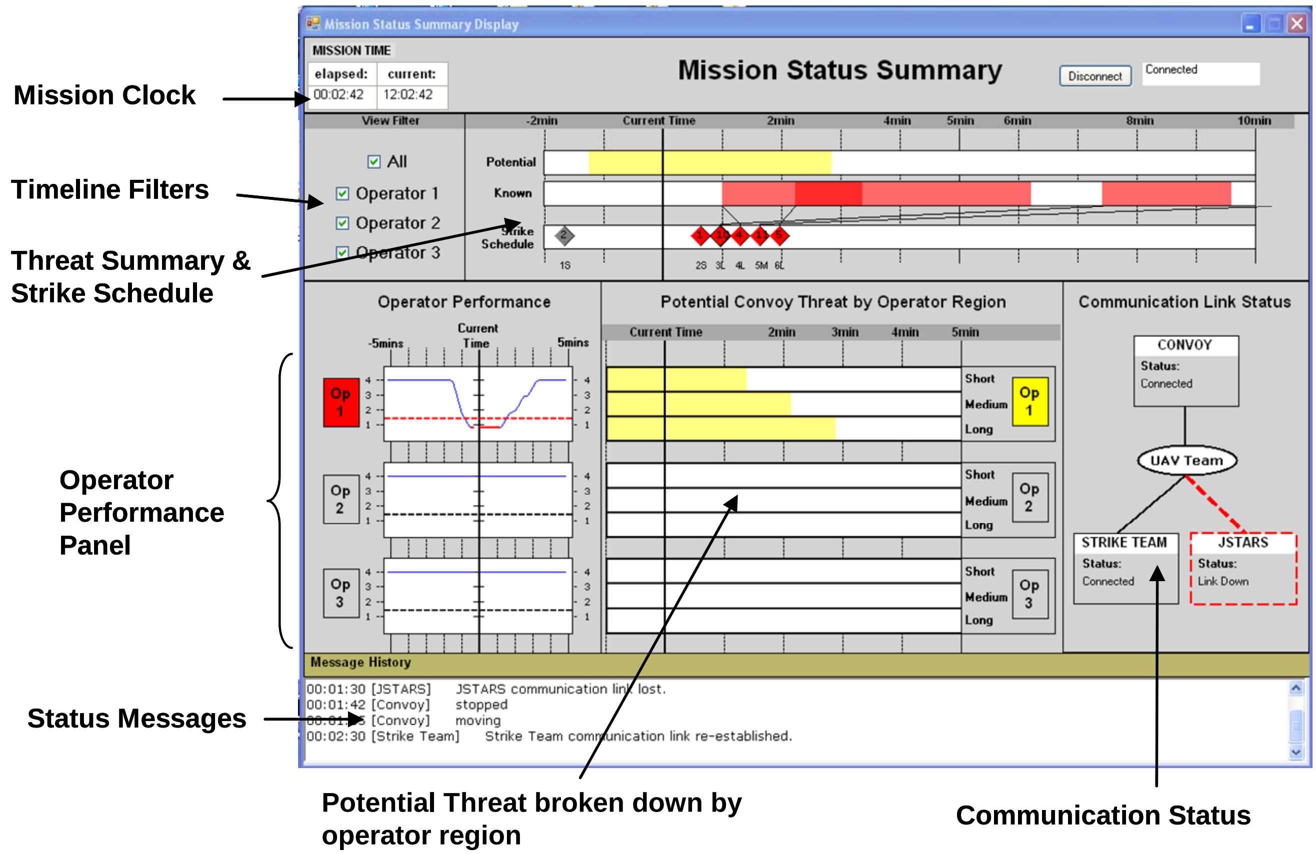

Figure 7. Mission Status Display.

will turn yellow. Also, the corresponding operator AOI boundary will turn yellow in the Situation Map Display.

The Operator Performance time graphs show the current and expected Operator Performance, currently based on each operator's ISR performance and its current and expected impact on convoy safety. In particular, each point on the graph indicates the corresponding operator's ISR performance for the previous 30 seconds (for points in the future, this calculation is based on expected performance, based on current surveillance patterns and may change if the operator subsequently detects a target). If an operator's ISR performance begins to degrade, putting the convoy's safety in jeopardy, the operator's performance score decreases. When an operator's performance is or expected to become critically low (i.e., their surveillance performance is putting the convoy in critical risk of being attacked), the alert to the left of the corresponding time graph will turn red. Also, the corresponding operator AOI boundary will turn red in the Situation Map Display.

The Operator Performance time graphs and Potential Convoy Threat Summary timelines help satisfy the operator performance and health and status information requirements from the CTA. In addition, the visual alerts provided on both the Situation Map and Mission Status Displays help satisfy the alert and feedback information requirements from the CTA.

The Mission Status Display also provides an up-to-date view of the UAV team's current connection status to the external contacts. When the UAV team is connected to all external contacts, the connecting lines between the UAV team icon and the contacts are shown as solid black lines. When a communication link is lost, the corresponding connecting line is shown as a dashed red line and the corresponding contact icon is also outlined in a dashed red line. This link status display helps satisfy the health and status and alert and feedback information requirements from the CTA.

Finally, the Mission Status Display contains a message history box, which displays communication messages sent to the mission commander from team members and external contacts, as well as status messages from the system.

CONCLUSIONS AND FUTURE WORK

The paper proposed a set of large-screen displays designed to assist a mission commander overseeing a time-critical command and control operation involving a team of unmanned vehicle operators. These displays incorporate a number of design concepts aimed at satisfying design requirements generated from a cognitive task analysis of a mission commander's role in a representative time-critical ISR operation involving a team of UAV operators. These design concepts include various mechanisms for providing ongoing and expected status of team members' activity in relation to the overall mission goals, alerting mechanisms related to operator workload and task performance, and a novel timeline visualization designed to integrate information related to asset safety and planned strike operations.

In order to understand how well the proposed large-screen displays facilitate supervisory-level decision making, we are currently conducting a laboratory user experiment. Since the task scenario involves a futuristic UAV team mission, a software simulation environment was developed to emulate the activities of the UAVs (e.g. automatic route following and onboard automatic target recognition) and any complex operator-UAV interaction (e.g., UAV handoff between two operators, UAV re-routing, and sensor manipulations for target detection). In the study, participants assume the role of a mission commander overseeing a team of three UAV operators (played by members of the experiment team) who are each controlling three UAVs.

Initial results from this ongoing experiment indicate that participants find the activity awareness information integrated into the map display and the Threat Summary and Strike Schedule timeline visualization particularly useful for understanding the overall mission situation and prioritizing the team's current problems in the context of the overall mission priorities.

Although the designs proposed by this project used the concept of activity awareness to provide decision-support for the mission commander, the most effective information representation will continue to be explored as the project continues and as results from this and future studies are obtained.

REFERENCES

Bisantz, A.M., Pfautz, J., Stone, R., Roth, E.M., Thomas-Meyers, G. & Fouse, A. (2006). Assessment of Display Attributes for Displaying Meta-information on Maps. In *Proceedings of HFES 2006: Human Factors and Ergonomics Society 50th Annual Meeting*, October 16-20, 2006, San Francisco, CA, USA, HFES, pp. 289-293.

Carroll, J.M., Neale, D.C., Isenhour, P.L., Rosson, M.B. & McCrickard, D.S. (2003). Notification and Awareness: Synchronizing Task-Oriented Collaborative Activity. *International Journal of Human-Computer Studies*. 58, pp. 605-632.

Carroll, J.M., Rosson, M.B., Convertino, G. & Ganoe, C.H. (2006). Awareness and Teamwork in Computer-Supported Collaborations. *Interacting with Computers*. 18(1), pp. 21-46.

Dominguez, C., Long, W.G., Miller, T.E., Wiggins, S.L. (2006). Design Directions for Support of Submarine Commanding Officer Decision Making. In *Proceedings of 2006 Undersea HSI Symposium: Research, Acquisition and the Warrior*, June 6-8, 2006, Mystic, CT, USA.

Dudfield, H.J., Macklin, C., Fearnley, R., Simpson, A. & Hall, P. (2001). Big is better? Human factors issues of large screen displays with military command teams. In *Proceedings of People in Control (PIC'01): International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres*, June 2001, Manchester, UK, IEE, pp. 304-309.

Endsley, M.R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors*. 37(1), 32-64.

Jenkin, C. (2004). Team Situation Awareness: Display Technologies in Support of Maritime Domain Awareness. In *Proceedings of 7th Marine Transportation System Research & Technology Coordination Conference*, November 16-17, 2004, Washington, DC, USA.

Nehme, C.E., Scott, S.D., Cummings, M.L. & Furusho, C.Y. (2006). Generating Requirements for Futuristic Heterogeneous Unmanned

Systems. In *50th Annual Meeting of the Human Factors and Ergonomic Society*, October 16-20, San Francisco, CA.

Pester-DeWan, J., M., R.A., & Morrison, J.G. (2003). Knowledge Engineering for Command and Control Transformation at United States European Command (USEUCOM), Technical Report A148124, San Diego, CA, USA, Space and Naval Warfare Systems Center.

Rasmussen, J. (1983). Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distractions in Human Performance Models. *IEEE Transactions on Systems, Man, and Cybernetics*. SMC-13(3), 257-266.

Roth, E.M., Lin, L., Thomas, V.M., Kerch, S., Kenney, S.J. & Sugibayashi, N. (1998). Supporting situation awareness of individuals and teams using group view displays. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, vol. 1, Santa Monica, CA, USA, Human Factors and Ergonomics Society, pp. 244-248.

Scott, S.D., Rico, A.E., Furusho, C.Y. & Cummings, M.L. (2006). Designing Decision and Collaboration Support Technology for Team Supervision in Multi-UAV, Time-Sensitive Targeting Operations, Technical Report HAL2006-04, Cambridge, MA, USA, MIT Humans & Automation Lab.

U.S. Department of Defense (1999). Interface Standard, Common Warfighting Symbology, MIL-STD-2525B, 30 January 1999.

Ware, C. (2000). *Information Visualization: Perception for Design*: Morgan Kaufmann Publishers Inc.

ACKNOWLEDGEMENTS

We would like to thank the members of the Humans and Automation Lab for their thoughtful comments on this work. We also gratefully acknowledge Boeing Phantom Works for sponsoring this research.

Stacey D. Scott *is a postdoctoral associate in the Humans and Automation Lab at the Massachusetts Institute of Technology in Cambridge, MA. She obtained her Ph.D. in computer science at the University of Calgary in Calgary, AB, Canada and her B.Sc. in computer science and mathematics at Dalhousie University in Halifax, NS, Canada. Her research interests include human-computer interaction, information visualization, and computer-supported collaboration.*

Jordan Wan *is a master's student in electrical engineering and computer science at the Massachusetts Institute of Technology in Cambridge, MA. His master's thesis involves an extension of this project that investigates the design of interruption recovery aids for team supervisors.*

Alma Rico *recently completed her bachelor's degree in electrical engineering and computer science at the Massachusetts Institute of Technology in Cambridge, MA and is currently on a student exchange program in Italy.*

Carina Furusho *recently completed her bachelor's degree in mechanical and aeronautical engineering at the Instituto Tecnologico de Aeronautica in San Paulo, Brazil and now works for Embraer, Brazil.*

Mary (Missy) Cummings *is an Assistant Professor of Aeronautics and Astronautics and director of the Humans and Automation Lab at the Massachusetts Institute of Technology in Cambridge, MA. She obtained her Ph.D. in systems engineering from the University of Virginia, her M.S. in space systems engineering from the Naval Postgraduate School, and her B.S. in mathematics from the United States Naval Academy. She was a naval officer and fighter pilot from 1988-1999. Her research interests include human supervisory control, human-unmanned vehicle interaction, bounded collaborative human-computer decision making, decision support, information complexity in displays, and the ethical and social impact of technology.*