Mission Commander Displays in Time-Sensitive Targeting Operations

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Abstract
Tools for coordinating and managing information will be crucial for military operators to successfully execute missions as the military establishes a tenet of networked forces and especially as time-sensitive targets (TST) become more prominent in modern warfare. As part of the collaborative TST project simulation, this thesis proposes large-screen display redesigns that aim to provide decision-support for a mission commander supervising a TST mission. The TST scenario simulates a realistic futuristic operation, where operators managing highly-autonomous UAVs must secure an area possibly containing time-sensitive targets so that a convoy can safely pass. The first display was used as a situation map display, to visualize geographical information of targets and assets, while the second display was designed as a mission status summary display to view current and expected status information. Guided by the concept of activity awareness and display requirements resulting from a cognitive task analysis, the various components attempt to present the most relevant information that will allow the mission commander to make immediate informed decisions. Since most of the decisions made by the mission commander relate to the safety of the convoy or the performance of the UAV operators, the major changes relate to these tasks. A timeline depicting threat envelopes for time periods where the convoy would enter a threat’s strike area was created. The operator’s surveillance performance is related to the convoy threat level on past, current, and expected radar plots. The revised design utilized the touch-screen capability and grants the mission commander more control over the amount of information he views by selecting filter buttons. Although this design attempts to enhance decision-support for the mission commander, the displays require future iterations and use in the testing environment to assess their usability in TST operations.

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1 Introduction

Effective team collaboration and timely decision-making significantly influence the outcome of time-sensitive military operations. Unfortunately, the increasing complexity introduced by recent moves towards network-centric operations (NCO) in U.S. military operations provides additional challenges for efficient decision-making. As military operations move from separate services (Army, Air Force, and Navy) towards one unified joint forces, U.S. military procedures will more often consist of co-located and distributed teams composed of operators from different services often at different global locations. Military operations which require extremely quick decision turn around, such as operations dealing with time-sensitive targets (TST) like improvised explosive devices (IEDs), are particularly challenging in NCO teaming environments. Operators in TST environments not only have to manage overwhelming amounts of target-related information but also have the overhead of communicating and coordinating with co-located and distributed team members. Given the increasing trend for modern hostile forces to employ unconventional weapons such as IEDs and suicide bombs, the success of TST operations are becoming critical to current and future military operations. Providing TST teams with effective tools for communicating and coordinating their efforts is key to enabling their success.

However, despite advances in collaborative technologies and extensive research in military teams, decision-making and collaborative activities continue to be time-consuming and often ineffective in the TST domain. Research in military collaborative technologies has mainly focused on its impact on individual, networked operators working at a distance, rather than on teams, such as TST operations teams, which often consist of both co-located and distributed members. As the military continues to adopt more network-centric operations, collaborative technologies will not only have to be evaluated in the general military domain but they will also need to accommodate the limitations and particular operating structures of collaborative TST missions.

For this reason, the Humans and Automation Laboratory (HAL) Collaborative TST project aims to improve teamwork in TST operations by investigating possible supporting technologies. Since TST operations sometimes include remote team members and often require co-located operators to continuously attend to critical information on their individual workstations, it is often difficult for operators to gather key information regarding their teammates’ activities. Thus, this project is exploring ways to provide TST collaborators activity awareness, a design approach focused on improving planning and coordination in collaborative activities through intelligent sharing of group activity information. The project hopes to leverage previous HAL projects related to TST operations and investigate the impact of providing activity awareness to enhance collaboration in this setting.

The goal of this thesis was to investigate large-screen display designs that would improve TST team collaboration by providing activity awareness for a mission commander overseeing a networked TST operation. This report details the display requirements resulting from a modified Cognitive Task Analysis (CTA) performed on a representative
TST task scenario and the preliminary design for large-screen displays. Before describing the results of this research, previous work relevant to this project are discussed. Next, the HAL Collaborative TST project scenario and physical system are described. The report then details the requirement generation process, evaluation of previous display designs based on these requirements, and re-design of these displays for the team supervisor decision-support displays followed by the results and discussion. Finally, possible extensions, improvements, and future work are described.

2 Background

The work performed in this project relies on concepts and ideas resulting from work performed in previous research. Although the literature on collaborative TST technology is slim, the following section details three previous works that influenced the approach and methodology of this project. First, the Multiple Aerial Unmanned Vehicle Experiment (MAUVE) single-operator display design developed by HAL researchers is described. Then we explore the concept of activity awareness by looking into the Virtual School project. Lastly, the Cognitive Task Analysis display generation approach used in this project is explained.

2.1 MAUVE Displays

The resulting work detailed in this report stems from previous work on the MAUVE test interface. The virtual TST simulation enables an operator to supervise four highly-autonomous Unmanned Aerial Vehicles (UAVs) responsible for destroying a set of time-sensitive targets. This dual-screen simulation test bed was developed to investigate the effect of levels of automation on individual operator performance, specifically on their ability to schedule tasks and maintain their payloads (Cummings & Mitchell, 2005). The initial UAV routes and target assignments are pre-defined, but the operator has the ability to change the course of a UAV as unexpected events arise. The operator’s main duty is to monitor the progress of the UAVs, but he can also change aspects of the mission and in some cases arm and fire payloads during a critical event.

There are six high-level actions that each UAV supervised by the operator can perform: 1) following a path to targets, 2) loitering at pre-determined locations, 3) arming payloads, 4) firing payloads, 5) performing battle damage assessment\(^1\), and 6) returning to base.

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\(^1\) Battle damage assessment (BDA) is the post-strike process that determines whether a weapon successfully hit a target.
Figure 1. MAUVE simulation navigation display depicting a map display, a mission time window, and a mission planning panel (Cummings & Mitchell, 2005).

Figure 1 depicts the MAUVE navigation display consisting of three major components: map display, mission time window, and a mission planning panel. The map display contains icons for the UAVs, targets, waypoints, loitering patterns, and dynamically-changing danger zones. Waypoints, loiter points, and targets can be changed using the mission planning panel on the left, which can be useful during unexpected events as real-time re-planning is required. The most critical function of this display is the “Request TOT Delay” button which allows the operator to change the time-on-targets (TOTs) time window for targets assigned to a particular UAV. In MAUVE, the probability that a request is accepted depends on how far in advance before the deadline the request is made. An operator could request a delay for several reasons including: 1) The current TOT indicates that the target will be missed and 2) To mitigate a future high workload. TOT events are critical since they are part of a coordinated strike with multiple agencies (Cummings & Mitchell, 2005). Also, the mission time window above the map display depicts the current and end time, as well as the time elapsed and remaining.
Figure 2. MAUVE status display showing timeline, chat history, and message updates (Cummings & Mitchell, 2005).

The companion screen to the navigation display is shown in Figure 2. This display aimed to provide decision-support for re-planning activities through a UAV status window, chat box, UAV health and status updates, and a decision support window. The chat box on the bottom-left allows an operator to communicate with fellow teammates (simulated for MAUVE experiments). Next to the chat box is a message window containing notifications concerning the health and status for each UAV. The rest of the display contains a schedule of events timeline besides each UAV, which simplifies standard air tasking order (ATO) data and combines it with mission planning information. Since ATOs contain a large amount of information such as which aircraft have been assigned and times on targets, several versions of this component were developed to investigate various levels of automation for assisting operator decision-making throughout the MAUVE experiments.

The operator displays for the collaborative TST project were originally set to be an expansion of the MAUVE displays. Though a design decision was made to develop a separate set of operator displays for the collaborative TST project, the underlying tasks and goals are very similar. As a result, the MAUVE design will have a large influence on the future operator workspace design approach, especially for the project’s level of automation decisions. At the current phase of the project, the MAUVE experiment helped establish a task scenario. Moreover, the MAUVE operators and mission
commander in the current TST project both have to overcome the significant cognitive control issue of managing large-amounts of data and executing real-time decisions with possible high-risk consequences. Therefore, the MAUVE displays will aid in developing display components for the large-screen displays to support the decision-making process for the mission commander.

2.2 Activity Awareness

John M. Carroll and his fellow researchers from Virginia Tech set the foundation for activity awareness studies in 2002 during their work on notification systems in collaborative software. In a paper published by the International Journal of Human-Computer Studies, they wrote that the activity awareness concept “builds on proper conceptions of social and action awareness, but emphasizes the importance of activity context factors like planning and coordination” (Carroll et al., 2003). They proposed notification systems that would support remote collaborative activities in an educational setting.

The three awareness concerns: social, action and activity awareness are listed in Figure 3, along with the suggested information needed to support it. Action awareness and social awareness were used as a background for activity awareness, and as indicated in the figure, activity awareness encompasses both since it requires the system to provide information on changes to shared items and state of collaborators.

<table>
<thead>
<tr>
<th>Awareness concern</th>
<th>Information needed to address this awareness concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social: &quot;Who is around?&quot;</td>
<td>Presence of collaborators; features of an online collaborator that convey motivational state or attitude; timing, frequency, or intensity of individual or group activity or communication</td>
</tr>
<tr>
<td>Action: &quot;What is happening?&quot;</td>
<td>Timing, type, or frequency of collaborators’ interactions with a shared resource; location and focus of collaborators’ current activity</td>
</tr>
<tr>
<td>Activity: &quot;How are things going?&quot;</td>
<td>Creation or changes to shared plans, evaluations, or rationale; assignment or modifications of project roles; task dependencies based on roles, timing, resources, etc.; exception handling</td>
</tr>
</tbody>
</table>

Figure 3. Awareness concerns addressed in Virtual School research (Carroll et al., 2003)

Their collaboration initiative (set in an educational setting), called the Virtual School system, contained several shared collaboration and awareness tools to help students build science projects and experiments. The main tool worked similar to a science notebook, allowing students to plan and organize tasks, a text editor for writing reports, and a shared whiteboard for sketches. Several communication tools (chat, email, and videoconferencing) were available for students to communicate in or out of the classroom. Lastly, a session manager displayed the status of team members, notebooks in use, and a notice board of edited files (Carroll et al., 2003).

The Virtual School paired physics high school students with physical science middle school students to carry out experiments and projects using the software tools. Students were divided in distributed groups of about 4-5 students and asked to complete a set of experiments and deliver a final report within a specified deadline. Synchronous
networked sessions lasted about half an hour per week. Despite attempting to establish “common ground” between the networked teams and support activity awareness, the Virtual School had various breakdowns which they divided into four contributing factors: situation factors, group dynamics, task factors, and tools. Most important to our study of TST activity awareness, are the problems relating to group dynamics and task factors. Through teacher and student feedback, researchers realized that the Virtual School was unable to create trust between the middle school students and their high school counterparts. Furthermore, teams were unable to complete tasks because of failure of communication and goal coordination.

![Virtual School large-screen display classroom timeline](Carroll et. al, 2003)

**Figure 4.** Virtual School large-screen display classroom timeline (Carroll et. al, 2003).

To motivate the development of trust between team members and improve coordination, the designers introduced changes to their user software as well as the document-oriented timeline on student workstations and on a large-screen display pictured in Figure 4. The timeline indicates important deadlines, milestones, and document revisions so that teams can easily view what they need to complete by viewing recent project history. The large-screen display aims to serve as a team situation status reminder by communicating mutual context information to the entire group. Teachers can also supervise the status of the class and subgroups. The unobtrusive information line at the top of the display supports awareness of events that affect any of the collaborators, as it displays updates and student events affecting the project deadlines.

The Virtual School system established the concept of activity awareness to enhance collaborative activities and simulated the concept in a networked educational environment. Determining designs that provide effective activity awareness during TST teaming operations is one of the underlying goals of this thesis.
2.3 Hybrid Cognitive Task Analysis

Since the Collaborative TST project scenario is set in futuristic battlefield environment, the Hybrid Cognitive Task Analysis (CTA) presents a useful framework for developing display requirements (Nehme, et. al., 2006). The Hybrid CTA extends the applicability of the traditional CTA to revolutionary systems. The traditional CTA approach requires subject matter experts, documentation, and previous 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 display requirements. This section describes the Hybrid CTA process, which was used to generate the design requirements for this thesis.

The Hybrid CTA compensates for the lack of such resources 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 information and display requirements from the decision ladders.

The scenario task overview serves as the foundation of the Hybrid CTA (here on simply referred to as CTA). In this step, 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 sub-tasks for each of these sub-goals, finally leading to individual sub-tasks.

Next, the event flow diagram stems from the tasks and subtasks detailed in the scenario task overview. The event flow diagram sketches the mission execution phase into sequential events and lists mission planning assumptions. Most importantly, it demonstrates the dependency between events as well as temporal constraints. Three basic event types are used: loops (iterative events that occur until another predetermined event arises), decisions (an event requiring knowledge-based input from an operator), and processes (a task requiring some human-computer interaction).

The third step generates situation awareness requirements based on the temporal constraints of the event flow diagram for each phase and subtasks in the scenario task overview. Each requirement is divided into the following levels: perception, comprehension, and projection, which represent the essential mental processing levels needed to gain situation awareness (Endsley, 1995).

Lastly, the CTA attempts to generate an operator’s thought process by generating decision-ladders. Decision ladders seek to represent an operator’s decision-making process and to help understand what knowledge is needed for them to make particular decisions by expanding 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. A traditional cognitive systems decision ladder can be supplemented with corresponding display requirements and/or levels of automation.

3 Project Overview

The Collaborative TST project at MIT’s Humans and Automation Laboratory (HAL) is working to develop display technology that provides effective activity awareness to teams of TST operators to ultimately improve collaboration in a TST environment. To better understand the kind of support required in TST operations, a Generalized Team TST (GTT) task was developed to simulate the type of collaboration that might exist. Based on the time-sensitive targeting process, the GTT was designed under certain requirements to emulate future TST situations (Scott & Cummings, 2005).

The GTT scenario consists of a team collaborating to secure a large geographical area to ensure the safe passage of a political convoy before and during its trajectory. The team involves a mission commander supervising a team of 3 to 4 operators utilizing futuristic, highly autonomous UAVs to secure the area. Each UAV operator is equipped with four UAVs, three standard UAVs and one laser-embedded UAV to allow an external Strike Team locate targets of interest identified by the UAV operators. Operators perform three main tasks: Intelligence, Surveillance and Recognition (ISR), Strike (STR), and Battle Damage Assessment (BDA), to complete the mission.

Aside from the core team, external assets include a satellite, a Strike Team, and an Airborne Warning and Control System (AWACS). The satellite tracks the position of the convoy; the Strike Team engages targets upon order of the UAV operators, while AWACS provides location and battle damage assessment for enemies. Furthermore, enemy weapons have varying degrees of distance capabilities (long-range, medium-range, and short-range) and different priority classifications (high, medium, and low priority).

To simulate such a collaborative setting, HAL has setup a reconfigurable team environment. The environment consists of the following components:

- 3 Networked large-screen wall displays with touch-screen technology for depicting a summary of situation information
- 4 Reconfigurable operator stations equipped with three displays that allow the operators to supervise and control their UAVs. There are two ways in which the stations can be changed: their relative seating arrangement as well as the three displays at each workstation.
- Handheld and tablet displays for use by the mission commander.

The various components and a suggested setup are depicted in the concept diagram shown in Figure 5. Not pictured in the testing environment is the data capture equipment (such as recording equipment) that will aid in the future evaluations.
Figure 5. The reconfigurable collaborative environment containing (A) large-screen wall displays, (B) reconfigurable operator stations, and (C) mobile technology (Scott & Cummings, 2005).

Figure 6 shows the current laboratory setup at MIT, with the reconfigurable operator stations. The large-screen displays are expected to be installed in the near future.

This report focuses on the design of the large-screen displays. The methodology used to generate these designs is detailed in the following section.

4 Methodology for Designing the Team Supervisor Decision Support Displays

Large-screen wall displays are becoming a common part of military command and control environments and will be an integral part of the HAL testing environment. These displays are often used to depict a mission summary or a ‘big picture’ to team members usually in the form of a map or situation status. All team members can potentially view information on the large-screen displays, which introduces challenges for determining what information should be displayed on them. However, anecdotal evidence from large
display use in current command and control settings suggest that these displays are primarily used by mission commanders. Also, since it is particularly important for a mission commander to maintain awareness of the overall mission status, it was decided to gear the large-screen display requirements towards providing supervisory situation awareness.

4.1 Cognitive Task Analysis

The task scenario being used in the project involves futuristic, highly autonomous UAVs, which are beyond today’s UAV technology and, thus, beyond the scope of current TST operations. Therefore, the Hybrid CTA discussed earlier was used to derive the information requirements needed to support a mission commander in this futuristic scenario. The mission commander is responsible for overseeing the entire mission which entails supervising operator performance and ensuring the safety of the convoy at all times. To better understand the mission commander’s role in the scenario, what information is necessary for him or her to complete each phase of the mission, and possible problems that could arise, Carina Furusho, another HAL student, completed and identified the necessary situation awareness requirements for each phase of the mission.

This thesis continued the CTA process, starting with the completion of the CTA event flow diagram displaying the temporal events in the mission. Each critical event that resulted from a decision event required further investigation into the knowledge and information necessary to support the mission commander’s decision-making process. Therefore, decision-ladders detailing the decision process leading to a critical event were created. Finally, display requirements were added to each decision-ladder based on the information that a mission commander might need to make a decision.

Furusho’s scenario task overview and situation awareness requirements are listed in the appendix, while the CTA elements generated during this thesis, including the event flow diagram and the decision ladders with corresponding display requirements, are discussed in the Results section.

4.2 Evaluation, Re-Design, and Implementation of Displays

The display requirements resulting from the CTA process were then used to evaluate preliminary display designs, which had been completed by other project members in an earlier phase of this research project. We verified that each requirement was effectively addressed in the large-screen displays, and amended the design to include any missing decision-support as indicated by the results of the CTA.

The initial display designs started by Carina Furusho and Sylvain Bruni (another HAL student) and the revisions generated for this thesis are discussed in the results.

The finalized version of the displays, which is being implemented in Visual Studio .net in C#, has begun and will be continued by other project members. These programming tools were chosen because of their usefulness for rapidly prototyping graphical interfaces.
5 Results and Discussion

The following sections demonstrate the results of the CTA and redesign of the supervisor decision-support displays. Each component is described and its contribution to the goal of the project is discussed.

5.1 Results of Cognitive Task Analysis

Figure 7 depicts the event flow diagram constructed from the scenario task overview. The rectangles at the top show the three main mission phases: mission planning, mission execution, and mission recovery. Below the earliest phase, the mission planning phase, is a parallelogram listing the tasks which are assumed to be completed prior to the mission execution phase (our primary concern): each operator is given a pre-defined area of surveillance, and UAV search routes are defined. Moreover, diamonds depict decisions, hexagons represent loops, and blue rectangles depict processes involving human-computer interaction. Each decision results in a yes or no answer, which leads to another event.

In the case of the mission commander, the main mission execution decision (D1) establishes whether the convoy has exited the possibly dangerous geographical region. If the convoy has exited the region, the mission proceeds to the third and final phase, mission recovery, otherwise the mission commander enters a monitor team status loop (L1). Monitoring the team status consists of watching out for two main things: the status of operators and the convoy safety.
The mission commander can choose to hold back the convoy if he finds that the convoy will soon be in a potential threat situation that would be alleviated if the convoy stopped, as shown by (P2). If a convoy is holding, the mission commander can decide to release the convoy if it presently safe to do so. The bulk of the mission commander’s decision-making surround operator status events. An operator can be found to be overloaded, in which case the mission commander can decide to split the overloaded operator’s region and assign a spare operator to half of the region and lighten the overloaded operator’s workload. In the case of multiple overloaded operators, the mission commander will have to determine the highest priority region and proceed as appropriate.

Four main decisions (D3, D4, D5, and D8) 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 (Figures 8-11; larger versions of these diagrams are included in the appendix). The left-side of each decision ladder depicts the states of knowledge in ovals and information-processing activities in rectangles leading up to a decision, while the right-hand side shows the actions necessary to execute a decision. Each ladder begins with an activation event. The corresponding display requirements for relevant states in a decision-ladder are modeled in blue callout figures besides the corresponding state.
Figure 8. Decision ladder (augmented by display requirements) leading to a holding back convoy event.

For example, Figure 8 depicts the decision ladder with corresponding display requirements for detecting if a release order should be sent to a stopped convoy. If the mission commander notices that the convoy is holding and that there are no imminent threats to the convoy, he could decide to release the convoy. Before he can reach a decision, the mission commander must first obtain more information to be certain that once the convoy moves it will not be placed in a dangerous situation, as shown by the activities on the left, which cite a strike schedule, surveillance of regions, and capabilities of known targets. These elements will aid in determining the current threat level of the convoy and perceive its future threat level. Once the mission commander decides to release, he must transmit his decision to the convoy and perceive that the convoy receives his command as shown on the right side. In order to proceed from the activation states to subsequent states, the mission commander must have access to supplemental information from the displays as shown in the display requirements.
Figure 9. Decision ladder (augmented by display requirements) leading to identification of overloaded operator.

Figure 9 shows the decision ladder for detecting an overloaded operator. The mission commander initiates a decision when an operator’s region is not being surveyed fast enough or an operator is not engaging high-priority targets fast enough. In order to decide whether an operator is overloaded, the mission commander will need display information that would give him a better idea of the status of each of the operators and of their current and expected actions and workload levels. After deducing which operators are overloaded, he can decide whether an operator should be assisted based on the time until an intervention takes place.
Figure 10 displays the information processing activities and knowledge states for deciding if the convoy is or will be in a potentially threatening situation. This decision will trigger when the convoy is about to encounter a region that has not been surveyed or will possibly be in danger due to a detected target. Due to the uncertainty of the unsurveyed region, the mission commander must perceive the threat level given the range of known targets and the time until they will be eliminated. To mitigate a high-level threat, he can decide to send a hold request to the convoy. Once again, the right-hand side depicts the communication display requirements.
Lastly, Figure 11 depicts the decision ladder and associated display requirements for deciding whether the spare operator is being underutilized. When the mission commander seeks to alleviate an overloaded operator but the spare operator has already been assigned a region, he must decide where the spare operator would be most efficiently used to ensure the safety of the convoy. Various aspects of the overloaded operator’s region and the spare operator’s current region need to be displayed so that the mission commander can make a valid comparison. Most importantly, he must keep in mind the current and near future status of the convoy. If the overloaded operator’s region requires immediate attention, then a reassignment request must be sent to the spare operator.

The numerous display requirements stemming from the four decision ladders helped us evaluate the initial large-screen displays and propose revisions. Table 1 below lists the display requirements resulting from all of the decision ladders. Some display requirements reference similar type of information, but are needed in different situations.
<table>
<thead>
<tr>
<th>Decision</th>
<th>Display Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>If holding back convoy, can release? (D3)</td>
<td>(1) Visual alert and possible audio alert of convoy holding; threat situation as shown by targets within threat envelope visual</td>
</tr>
<tr>
<td></td>
<td>(2) Regional map depicts threat locations and uncertainty of surveyed areas. Simultaneously depict information on known targets as well as up to date strike schedule.</td>
</tr>
<tr>
<td></td>
<td>(3) Display measurement of threat level based on threats within envelope</td>
</tr>
<tr>
<td></td>
<td>(4) Display strength of convoy communication link and availability</td>
</tr>
<tr>
<td></td>
<td>(5) Display convoy acknowledgement if release received, and updated positioning of convoy</td>
</tr>
<tr>
<td>Is there an overloaded operator? (D4)</td>
<td>(6) Automated overall summary of current and expected future surveillance performance</td>
</tr>
<tr>
<td></td>
<td>(7) Display current state of operator surveillance and prosecution time versus ideal times per target; differentiate high-priority target times</td>
</tr>
<tr>
<td></td>
<td>(8) Visual depiction of threat envelope within operator’s region, time until convoy enters region, details of expected surveillance path in near future, and strike schedule for each operator</td>
</tr>
<tr>
<td></td>
<td>(9) View operator’s future expected state up until expected time to get assistance. Clock indicating time until convoy enters region.</td>
</tr>
<tr>
<td>Is convoy currently or soon to be in a potential threat situation? (D5)</td>
<td>(10) Visual and audible alert of convoy entering unvisited region or threat within threat envelope</td>
</tr>
<tr>
<td></td>
<td>(11) Display map of convoy location as well as location of targets, and resulting threat envelope indication. Updated strike schedule with target of interest highlighted if listed. Uncertainty of surveillance shown in threat envelope path</td>
</tr>
<tr>
<td></td>
<td>(12) Display time until convoy enters dangerous region, capabilities of high-priority threats, expected time until threats are eliminated, and expected time until convoy receives and executes hold request</td>
</tr>
<tr>
<td></td>
<td>(13) Strength and availability of communication with convoy displayed</td>
</tr>
<tr>
<td></td>
<td>(14) Display convoy ACK and updated positioning of convoy</td>
</tr>
<tr>
<td>Is the spare operator currently being underutilized? (D8)</td>
<td>(15) Display details of assigned region containing map such as: targets, surveillance coverage, and strike schedule alongside overloaded operator’s region</td>
</tr>
<tr>
<td></td>
<td>(16) Display time until convoy enters region</td>
</tr>
<tr>
<td></td>
<td>(17) Display reallocation/removal of region on map</td>
</tr>
</tbody>
</table>
5.2 Display Designs

The results of the CTA along with the concept of activity awareness guided the design of two large-screen, interactive situation displays: a situation map display which visualized positional information of UAVs and threats in a geographical context; and a mission summary display that visualizes current and expected status information such as surveillance performance for each UAV operator, communication link status to external resources, and expected target strike schedule for identified targets.

5.2.1 Map Display

The initial large-screen map display is shown in Figure 12 below while the re-design is shown in Figure 13 and 14.

![Initial map display](image)

**Figure 12.** Initial map display for large-screen mission commander display designed by Carina Furusho.
Both map displays show the convoy as a blue rectangle icon traversing a path as shown by the black line on the map. The path is divided into three operator regions delineated by dashed rectangles. The new design changed the outline color to black to indicate nominal situations, and high-risk regions are shown in red. UAV icons are shaded by their type (orange for laser-embedded, blue for standard, and gray for when they are no longer available) and contain their name. Diamonds depict targets, which are color coded based on their current status (red= awaiting a strike, orange= strike occurring, gray= destroyed). A mission clock on the top-left shows the elapsed, current, and remaining time of the mission. Regions which have not been searched within some pre-defined time frame are shown by varying shades of gray, depending on the time since the region was last visited in the initial display. For simplicity, there is only one shade used in the updated displays, which indicates the area has not yet been searched.

The major changes to the map display are the surveillance path buttons, the target window functionality (Fig. 14), and the convoy threat summary. To begin, the updated map display contains an additional surveillance path panel. The panel to the left of the screen allows the mission commander to use the touch-screen functionality by selecting one or more of the operator buttons to view the predicted surveillance path of the UAVs in the selected regions as shown by the dashed lines in operator 2’s region in Figure 13. The mission commander can also filter the paths within the region by touching a UAV’s region on or off. The surveillance path feature could be enhanced by showing tick marks for pre-defined time increments on the UAV path and allowing a drop-down menu when clicking an operator button that gives different prediction times.
Next, the re-designed map display now offers target window functionality to show information on a target when it is selected as shown in Figure 14. Initially, the display always showed the threat’s name. For now, the target window lists the minimum information inferred by the display requirements: target name, weapon capabilities, and time until the convoy enters its strike zone. However, more information such as the distance between the convoy and the target, the target’s threat level, or time until it’s scheduled elimination (if it is on the strike schedule, which is discussed later) could be added for redundancy as these details are displayed elsewhere, as will be discussed later. The color of the window was chosen to match the status of the region, but could be changed to reflect the threat level of the target.

Lastly, the detailed path shown at the bottom of the preliminary map display was changed in the re-designed map display to show a timeline view. In the initial map display, the distance-based, path-view partitions the path into regions, which show the uncertainty of the region by the different shades of gray, the UAV positioning with respect to the path, and the target distance from the path. The target colors correspond to their threat level, while their size shows their range capabilities. Since the map contains most of this information already, a timeline view would more effectively augment the map information. The convoy threat summary will show when the convoy enters a different region by dashed lines as before. However, the time divisions contain no icons, instead they show threat envelopes. Based on a known target’s weapon capability, a circular perimeter can be defined around the target. If this range overlaps with the path of the convoy, then there is a region or “envelope” in the path of a duration determined by the speed of the convoy and the overlap, where the convoy’s safety could be in danger. Threat envelopes for known targets are shown in a transparent red color. A touch-functionality could also display a target’s information window by clicking a threat envelope. Yellow threat envelopes represent time periods where the convoy is expected, based on the current mission plan, to pass through or within weapons range of a non-
surveyed area; thus, representing a possible threat situation. Threat envelopes are eliminated from the timeline when the threat is eliminated. The timeline was changed to a gray rectangle and shows uncertain regions by dark gray blocks. The duration for which the threat envelopes are shown is 15 minutes; however the most appropriate time requires further investigation.

The enhancements added by the aforementioned components satisfy many of the display requirements, including (2), (3), (8), (11), and (15) from Table 1. The majority of the display requirements are addressed by the second large-screen display.

### 5.2.2 Mission Status Summary Display

The initial mission status summary displays are shown by Figures 16 and 18, while the re-designs are shown in Figures 17 and 19.

![Figure 15. Initial Mission Status Display](image)

The updated display visualizes the information on the initial display more clearly and efficiently and adds components to satisfy the display requirements. Four main decision-support data make up the mission status display: a strike schedule, operator performance measurements, overall team performance measurements, and communication information. First, the display requirements repeatedly mention the need for a strike schedule. The initial strike schedule depicted in Figure 15 shows a strike schedule divided into strips for each operator. The target icon and name as well as its assigned
UAV-LE are shown in the timeline, which uses gradient shading to demonstrate the availability of the strike team. After careful consideration, the strike team availability was eliminated from this version of the design. For simplicity, coordination with the strike team will be a task solely performed by individual operators not requiring supervision by the mission commander. In the updated design the strike schedule is paired with the threat envelope timeline discussed in the map display as shown at the top of Figure 16. The strike schedule shows one timeline strip containing the scheduled targets labeled by the operator assigned to the region where the target is located. This labeling eliminates the need for displaying the UAV icon or target details. Also, the separate individual operator strike schedules are combined into one overall strike schedule, which can be filtered by operator as shown by the buttons on the left. This functionality displays the same information more efficiently and gives the mission commander more control over which operator’s strike schedule to view.

Since the threat envelopes and strike schedules are both timeline-based, each threat envelope is connected to its corresponding threat by a straight line. This line gives the mission commander an idea of how far before or after the convoy encounters a target’s threat zone. Most importantly, a line sloping to the right displays critical danger to the convoy, since the target will not be eliminated by the time the convoy enters the target’s threat envelope. This event will also trigger a salient notification to the mission commander, as will be discussed below.

**Figure 16.** Re-Designed Mission Status Summary Display including communication panel, surveillance measurement panel, threat envelope timeline, and strike schedule.
Additionally, the communication panel located in the lower-right of both screens was slightly modified. The convoy, strike team, AWACS, and UAV icons are connected by straight lines whose thickness changes based on the strength of the communication link. In the initial design, each icon for the external assets only contained status information and the time of last communication. The updated design adds the time for the next available communication and the average duration for each cycle. This extra information gives the mission commander a better idea of the reliability of the link and informs him of the next possible opportunity to communicate with each external entity.

The new design combined the panels titled “wait times” and “overall team performance” into one “surveillance time” panel depicting relevant team member performance and the overall team performance measurements. The overall team performance panel in the initial display (Figure 15) shows a table matching target icons to the operator execution phase (ISR, STR, etc.) in which they are found, as well as an overall team performance versus time graph. To its left, the initial wait time panel shows histogram type measurements known as radar plots. Each of the axes in the radar plot corresponds to an operator performance measurement and is terminated by an operator button. The initial design showed the current and predicted measurements and allowed the mission commander to select an operator button that combines the wait time panel with the overall team performance panel into a more detailed wait time panel. The resulting panel hides the overall team performance panel into a more detailed wait time panel. The resulting panel hides the overall team performance measurements, adds the 5-minute past performance radar plot, and displays a detailed performance versus time graph for the selected operator as shown in Figure 17.

![Figure 17. Initial Mission Status Display for large-screen display designed by Carina Furusho including operator performance chart.](image-url)
Radar plots were found to be the most effective depiction for the operator performance measurements, as they allow multiple measurements to be displayed and easily compared so were carried over and enhanced in the new design, as will be discussed. However, the target-phase table did not satisfy any display requirements and was not considered valuable at this point of the design, and was therefore removed. On the other hand, the past, current, and future radar plots show relevant information when the mission commander is detecting an overloaded operator. A resulting “surveillance times” panel stemmed from the wait time panel from Figure 17 as shown in Figures 16 and 18.

When the operator selects an operator button on the radar plot, the chart is covered by a similar chart belonging to a single operator as shown in Figure 18. This view allows the operator to view the same information given by the radar plots in a clearer continuous line, without comparison with the other operators. As a result, only the set of buttons surrounding the current radar plot were necessary. Initially, the targets in an operator’s region were displayed beside the operator buttons on the current radar plot. Since the

By default, the lower portion of the panel depicts the average team performance chart (Figure 16). The initial chart showed the team performance timeline from -10 minutes until the current time. However, the display requirements support expected performance and not past performance, so the time axis was expanded from -5 minutes to +5 minutes, with current time at the center. The time variables were an arbitrary choice and will be changed when a more appropriate time is found after testing. Since these variables were set to match those of the radar plots, we kept past performance. The dashed line showing expected average team performance remained unchanged.
amount of healthy and active UAVs in each region highly affects the operator’s performance as well, UAV icons replaced target icons of the initial display. The detected target icons (shaded by priority level) are instead displayed below the horizontal time axis at the time they are found on the performance chart. These targets help the mission commander assess the amount of activity in an operator’s region, and identify the rate at which they are being found.

Since the main operator activity that affects the convoy’s safety (the mission commander’s main concern) is the detection of threats, operator performance measures their ability to detect threats quickly and efficiently. Although there may be other factors that affect an operator’s performance, at this stage of the project measuring performance based on surveillance serves to relate operator activity to the mission goal to safely transport the convoy through the area of interest. Operator scores relate surveillance coverage to convoy safety. These measurements range from zero to 100, where a zero indicates no threat to the convoy (ideal surveillance) and 100 indicate the highest-probability of the convoy being attacked (no surveillance). In order to score an operator based on this rubric, their region is divided into small square increments of a set size to be determined. Three virtual circles the radius of the three weapon ranges form three areas of possible threat around the convoy as shown in Figure 19.

![Figure 19](image)

**Figure 19.** Three convoy threat regions surrounding convoy formed by red circle (short-range), yellow circle (middle-range), and blue circle (long-range) will be used to measure operator surveillance performance.

Black (unsurveyed) regions in the inner short-range circle are given the largest weight, the middle ring formed by the boundaries of the inner circle and middle circle is given a smaller weight, and the outer ring is given the smallest weight. Since threats closer to the convoy have a higher probability of striking the convoy, they are considered higher-risk than those further away. As a result, unsurveyed regions where a threat could be located are given more importance. In other words, the black square increments in each of the three regions are counted and divided by the total number of squares in that region and then multiplied by the weight. For example, for the current implementation unvisited regions within the inner circle are given a weight of .5, those in the middle ring are given .3, and those in the outside ring are given .1. If 70% of the outer ring has been visited, 80% of the middle ring, and 90% of the inner circle, then the operator would be given a
score of 14% threat to convoy (since \(0.1 \times 0.5 + 0.2 \times 0.3 + 0.3 \times 0.1 = 0.14\)). For now, measurements will be calculated every 30 seconds, but can change as a more appropriate time step is found.

Operator surveillance performance is shown by the radar plots. The acceptable or ideal performance shown by the dashed blue triangle is to be determined. Expected measurements will be calculated by an algorithm that uses the average operator performance. If this predicted score is well above the normal, then the operator label will turn red and the connecting lines will turn red as they approach the operator’s score on the axis. This color change warns the mission commander of a possibly overloaded operator, and allows him to begin deciding whether any help would be necessary. Below the expected radar plot, a small table lists the highest-priority target in each operator region that could become a threat to the convoy if not executed (i.e. it has just been detected but has not been added to strike schedule, or it will not be struck in time). Of particular interest to the mission commander is the time until the convoy is endangered by the threat.

Finally, the status message display at the bottom of the screen shows status notifications. This display can be used to notify the mission commander of important events and decision made by the operators. The components discussed throughout this section together with the map display satisfy the display requirements listed in Table 1 and provide decision-support for the mission commander.

6 Looking Ahead

The proposed displays resulted from reviewing the initial displays based on the display requirements. The selected visualization is by no means the only or most effective way to display the information necessary. As a result, these displays are bound to go through changes as the cognitive needs of the mission commander become clearer. Components can be altered for clarity and/or aesthetic readability. For example, suggestions that have resulted from discussions are to add score numbers on all of the axes of a radar plots, to eliminate the emerging threat table and simply display the time until expected threat next to the operator name, and to display the group performance graph as a superposition of the individual average operator performances.

In order to determine the best manner to satisfy the large-screen display requirements and provide activity awareness, the collaborative TST project will test out the final iteration (or possible variations) of the design presented in this thesis by running GTT simulations with test subjects. The collaborative testing environment located at MIT will aid in evaluating the completed display design, particularly with feedback from military operators. However, the simulation requires that the operator displays be constructed as well. The results from this thesis will provide a valuable starting point for this research.

Although the display design aimed to enhance decision-support by providing activity awareness, the exact impact of this approach is to be determined. The testing
environment will allow us to consider how providing activity awareness changes the strategies for performing tasks, communication, and coordination in a TST domain.

Moreover, as the display designs are tested the scenario could be expanded or changed in many ways as appropriate. The tasks of each operator, enemy capabilities, and collaboration between operators and external assets could be changed. Each additional phase enhancement will make the simulation more similar to real-life operations, and will allow for more levels of automation.

7 Conclusion

As today’s military transforms into a more network-centric organization and as time-sensitive targets become increasingly salient in modern warfare, technology which supports and enhances operator performance in this environment will be necessary to ensure the success of TST operations. With this problem in mind, the goal of the collaborative TST project at the Humans and Automation Laboratory is to provide decision-making support to operators by investigating appropriate display technology. The testing environment, which will allow us to simulate a TST operation, is made up of individual workstations, large-screen displays, and other equipment available in real military operations. This thesis explored display requirements for the two large-screen displays and used the results to evaluate and re-design a set of preliminary displays in order to provide decision-support for the mission commander.

The display requirements were obtained by performing a cognitive task analysis on a general TST task scenario developed to simulate the TST environment. The role of the mission commander in this scenario is to supervise the work of four UAV operators, who are securing an area to ensure the safe passage of a political convoy. The display requirements extracted from the decision-ladders were then applied to the large-screen display design.

The resulting re-designed map and mission status summary displays more effectively provide relevant information to the mission commander, as the changes and additional components provide the information necessary for the mission commander to make crucial decisions. Major changes to the initial design include a threat envelope timeline depicting the moments in time where the convoy may enter the strike area of a threat. An operator performance measurement was established to give the mission commander an idea of an operator’s surveillance performance and relate its effect on the convoy’s safety. Changes also take advantage of the touch-screen functionality of the displays by adding several filtering buttons, and simultaneously giving the mission commander more control over the information he wants to view.

Although the designs proposed by this thesis used the concept of activity awareness to provide decision-support for the mission commander, the most effective information representation will continue to be explored.
8 Acknowledgements

I would like to thank Dr. Stacey D. Scott and Professor Mary L. Cummings for their valuable assistance and support throughout this project.

9 References


## Appendix

**Table A1.** Mission Commander CTA Scenario Task Overview by Carina Furusho.

<table>
<thead>
<tr>
<th>Mission Execution</th>
<th>Possible events</th>
<th>Problem</th>
<th>Solution Breakdown</th>
</tr>
</thead>
</table>
|                   | UAV-LEx down/ malfunction | • All operators and mCDR are notified about the loss  
 • When the next target is found by the UAVOPx, the team is notified that an UAV-LE is needed  
 • Operators that can handover their UAV-LE send a signal (or a message) and the mCDR decides whose UAV-LE will be handed over  
 • If no other UAV-LE seems to be available, the mCDR decides whether a UAV-LE should be handed over or not, according to their priorities and strategy. |
|                   | UAV down/ malfunction | • All operators and mCDR are notified about the loss  
 • Operators that can handover a UAV send a signal (or a message) and the mCDR decides which UAV will be handed over  
 • If no other UAV seems to be available, the mCDR decides whether a UAV should be handed over or not and if a re-zone should take place or not, according to their priorities and strategy. |
|                   | A Zone gets overloaded with targets | • The mCDR decides whether a re-zone should take place or not, according to their priorities and strategy.  
 • If authorized by the mCDR, a re-zoned new map is available for all operators  
 • All the routes should be reviewed  
 • The Situation Awareness Display is updated and an alert should notify the changes |

**Mission Planning**

Issues to be resolved in this phase:
- Each UAV will have initial routes programmed
- Each operator will have a pre-defined area under his/her responsibility

Helpful information for resolving these issues:
- Time average target destruction will take based on
  - UAV speed
  - transit time
  - engagement time: flagged EO imagery
  - sent/operator confirm/communicate with strike
team/strike team wait time)
- AWACS, satellite and strike team schedule

**Mission Execution**

**Basic phases**

**Phase goals**

| Phase Breakdown |
|----------------|----------------|
| ISR | • UAVOP monitors his region of coverage, while the UAVs search for IED  
 • AWACS, Satellites, strike team and the convoy detect additional enemies and communicate to the UAVOPs. |
<table>
<thead>
<tr>
<th>STR</th>
<th>- Strike</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• UAVOP receives ISR information from the UAV and requests engagement authorization from the Mission Commander</td>
</tr>
<tr>
<td></td>
<td>• The mCDR decides if the target should be stroke and either grants the authorization or denies it.</td>
</tr>
<tr>
<td></td>
<td>• When granted, the UAVOP orders the strike team to engage the target</td>
</tr>
<tr>
<td></td>
<td>• The strike team coordinates with the UAVOP a time window for the target engagement</td>
</tr>
<tr>
<td></td>
<td>• When the Strike team is ready to engage, the UAVOP places his UAV-LE to pinpoint the target to be destroyed, during the appropriate time window</td>
</tr>
<tr>
<td></td>
<td>• The strike team engages the target of interest</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BDA</th>
<th>- battle damage assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• UAVOP performs Battle Damage Assessment, based on information provided by their UAVs, by the strike team and by the AWACS.</td>
</tr>
<tr>
<td></td>
<td>• UAVOP analyzes the consistency to confirm the destruction of the target or to order a re-strike.</td>
</tr>
<tr>
<td>Phases/Events</td>
<td>Level I (Perception)</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------</td>
</tr>
</tbody>
</table>
| ISR           | - All agents position information  
- Satellite updated images of convoy’s position  
- Geo-spatial boundaries  
- Communication status with intelligence assets and strike team | - Error/alert message clarification  
- Vehicle’s limitations (on demand)  
- UAVOP status and performance  
- Each operator number of targets and their status | - Estimated time for each spot on convoy paths  
- Estimated position/speed of each target  
- Estimated wait times for each operator  
- Uncertainties  
- Currently planned UAV routes  
- Prediction of vehicle’s health and status |
| STR - Strike  | - Alert when UAVOP requires engagement  
- Visual feedback for engagement confirmation | - Target information from all intelligence assets  
- Acknowledgement of Strike Team status | - For each target type (GT, IED) how long a strike takes.  
- Distances, speeds and predicted striking time  
- Target speed, predicted position/time and uncertainties |
| BDA - Battle Damage Assessment | - Visual/audio feedback for confirmation of target destruction  
- All agents’ position information | - Target information from all intelligence assets  
- Communication status with intelligence assets and strike team | - Next scheduled strikes |
| UAV down/malfunction | - Visual/audio alert  
- All agents position | - UAVs parameters, associated events history  
- Further intelligence about the target that stroke the UAV  
- UAVs health and status | - Targets and status of each zone  
- Operators’ predicted workload  
- UAV limitations when predicted to exceed some safe region |
| A Zone gets overloaded with targets | - Visual/audio alert  
- Each zone targets and status  
- Operators’ current workload | - Operators’ workload in the recent past  
- UAVs health and status | - Operators’ predicted workload  
- Targets and status of each zone |
| Communication with: - UAVOP - AWACS - strike team | - Different types of notifications when somebody is trying to communicate according to how busy the mCDR is and how important is the message | - All players’ schedule and workload  
- Current communication connections among stakeholders | - Operators’ predicted workload  
- AWACS and Strike Team schedule  
- Predicted communication connections among stakeholders |
Figure A1. Larger view of CTA event flow diagram
Figure A2. Larger view of decision ladder (D3).

Activation: Threat situation was passed and convoy still holding (e.g. no known threat envelope for immediate future)

IDENTIFY If threat level will remain low after convoy resumes mission path

RECOGNIZE if the convoy is released, threat level will remain low for immediate future

Identify: Decide whether to request convoy resumption

Perceive convoy's current and future threat level (e.g. known targets' locations, weapon's range with respect to convoy, current strike schedule, and uncertainty of surveillance)

Display measurement of threat level based on threats within envelope

Regional map depicts threat locations and uncertainty of surveyed areas. Simultaneously depict information on known targets as well as the up to date strike schedule.

Display convoy acknowledgement if release received, and updated positioning of convoy

Perceive convoy receives hold release and is resuming mission path

Display convoy communications link is active

Recognize if convoy communications link is active

Send release request to convoy

Display strength of convoy comm link and availability

Display requirements

Monitoring

Execute: Convoy resuming progress

Visual alert and possible audio alert of convoy holding; threat situation as shown by targets within threat envelope visual

Display strength of convoy comm link and availability
Figure A3. Larger view of decision ladder (D4).

**Activation:** High-priority targets within an operator's region are not being prosecuted fast enough or region is not being surveyed fast enough.

**RECOGNIZE** if the situation might be under control by the time an intervention takes place based on expected operator performances, strike schedule, and delay time to obtain assistance.

**IDENTIFY** which operators (if any) have known targets that will not be destroyed before convoy enters weapon's range and which operators (if any) have areas which will not be surveyed before convoy enters possible threat envelope range.

**Interpret:** Decide whether to assist operator.

**Is there an overloaded operator?**

**Display Requirements**

**Perceive each operator's current and future surveillance performance and known targets to be prosecuted**

**Execute:** Attempt to support overloaded operator by utilizing spare operator.

**Display current state of operator surveillance and prosecution time versus ideal times per target; differentiate high-priority target times by listing hierarchically**

**Automated overall summary of current and expected future surveillance performance**

**Visual depiction of threat envelope within operator's region, time until convoy enters region, details of expected surveillance path in near future, and strike schedule for each operator**

**View operator's future expected state up until expected time to get assistance. Clock indicating time until convoy enters region.**

**Display current state of operator's surveillance and prosecution time versus ideal times per target; differentiate high-priority target times by listing hierarchically**
**Activation:** Detection of possible long-range weaponry or other threat that will pose a danger to convoy in the immediate future OR detection of some regions that are not being surveyed fast enough to ensure convoy safety.

**RECOGNIZE:** Whether holding convoy will diminish threat level.

**IDENTIFY:** If threat level will remain high after delay of implementing hold.

**Perceive convoy's current threat level based on known target's location and weapon's range with respect to convoy, current strike schedule, and uncertainty of surveillance (possible undetected threats).**

**Display time until convoy enters dangerous region, capabilities of high-priority threats, expected time until threats are eliminated, and expected time until convoy receives and executes hold request.**

**Display map of convoy location as well as location of targets, and resulting threat envelope indication. Updated strike schedule with target of interest highlighted if listed. Uncertainty of surveillance shown in threat envelope path.**

**Recognize if convoy communications link is active.**

**Send hold request to convoy.**

**Perceive convoy has received hold request and is holding.**

**Display convoy ACK and updated positioning of convoy.**

**Display convoy's ACK and updated positioning of convoy.**

**Visual and audible alert of convoy entering unsurveyed region or threat within threat envelope.**

**Execute:** Convoy is holding.

**Monitoring:**

**Interpret:** Decide whether to intervene on convoy route.

**Display Requirements:**

**Show potential threat situations.**

**D5**

*Is the convoy currently or soon to be in a potential threat situation?*

**Display of convoy's current threat level**

**Perceive convoy's current threat level.**
Figure A5. Larger view of decision ladder (D8).
Figure A6. Larger view of map display design including surveillance path for OP2.
Figure A7. Larger view of Mission Status Display including average operator performance chart.