

Interface Design for Unmanned Vehicle Supervision through Hybrid Cognitive Task Analysis

Jamie C. Macbeth¹, M. L. Cummings¹, Luca F. Bertuccelli², Amit Surana²

¹*Humans and Automation Laboratory, Massachusetts Institute of Technology, Cambridge, MA*

²*United Technologies Research Center, East Hartford, CT*

While there is currently significant interest in developing Unmanned Aerial Systems (UASs) that can be supervised by a single operator, the majority of these systems focus on Intelligence, Surveillance, and Reconnaissance (ISR) domains. One domain that has received significantly less attention is the use of multiple UASs to insert or extract supplies or people. To this end, MAVIES (Multi-Autonomous Vehicle Insertion-Extraction System) was developed to allow a single operator the ability to supervise a primary cargo Unmanned Aerial Vehicle (UAV) along with multiple scouting UAVs. This paper will detail the development of the design requirements generated through a Hybrid Cognitive Task Analysis (hCTA) and the display that resulted from these efforts. A major innovation in the hCTA process in this effort was the alteration of the traditional decision ladder process to specifically identify decision-making tasks that must be augmented with automation.

INTRODUCTION

Current-day Unmanned Aerial Systems (UASs) realize the vision of the pilotless remote-controlled aircraft that observes the world at a great distance. However, one projected evolution of these systems is extending to missions where an Unmanned Aerial Vehicle (UAV) is able to land in a hostile or dangerous environment and insert or extract cargo or personnel. Additionally, high level control of UASs from manned aircraft is expected to extend the range of these systems and improve operational teaming between manned and unmanned vehicles (United States Army, 2010). This work, a collaboration between the MIT Humans and Automation Laboratory and United Technologies Research Center (UTRC), focused on the development of a human operator interface for controlling multiple, heterogeneous UAVs in insertion and extraction missions.

In this scenario, the human user of the Multi-Autonomous Vehicle Insertion-Extraction System (MAVIES) supervises a Cargo UAV (CUAV) and two Scout UAVs (SUAVs) using a point-and-click graphical user interface. The task environment for insertion-extraction missions is assumed to be dynamic and rapidly changing. The general class of insertion-extraction missions includes both military and civilian scenarios, such as cargo resupply, medical evacuation, search and rescue, and tactical firefighting. To generate display information requirements for the MAVIES interface, a Hybrid Cognitive Task Analysis (hCTA) was performed. This analysis method derives the information requirements of the human interface from a set of operational tasks.

HYBRID COGNITIVE TASK ANALYSIS

The development of futuristic human interfaces poses a chicken-or-egg conundrum when the designers of a system seek to analyze a domain in order to derive interface design concepts, but no interface has ever been designed for the domain. In cases where no previous implementations of an interface exist, the hCTA extends traditional cognitive task analysis methods to generate information and functional requirements using

a scenario description and an enumeration of high-level mission goals. This method of analysis has four steps:

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

The hCTA method (Nehme, Scott, Cummings, & Furusho, 2006) has previously been used to generate functional and interface requirements for the supervisory control of multiple, heterogeneous unmanned vehicles (Scott & Cummings, 2006), for a mobile interface for utility repair workers (Tappan, Cummings, Mikkelsen, & Driediger, 2011), and for the development of an interactive in-cab scheduling interface for railroad locomotive operators (Tappan, Pitman, Cummings, & Miglianico, 2011).

Scenario Task Overview

The purpose of the initial step in the hCTA process, generating the scenario task overview, is to capture a more formal definition of the mission statement in terms of phases, representing high-level groupings of tasks, and of the tasks in each phase. The phases and tasks are oriented to particular goals and subgoals in the mission.

For MAVIES, five phases were specified for a single user operator controlling multiple UAVs in an insertion-extraction mission. They were named *Mission Assignment*, *Takeoff*, *En Route*, *Insertion-Extraction*, and *Return to Base*. In the *Mission Assignment* phase, the operator receives a mission, requests support, and prepares for mission commencement. At the *Takeoff* phase, the operator launches scout UAVs to determine a safe path and landing site for the CUAV. Then the CUAV takes off, beginning the *En Route* phase, where the user monitors the CUAV's progression to the landing site and the SUAVs escort the CUAV if needed. During *Insertion-Extraction*, the CUAV lands at the designated site, performs the on- and/or off-loading objective of the mission, and subsequently takes off. During this time, the SUAVs survey the area to assure the CUAV's safety

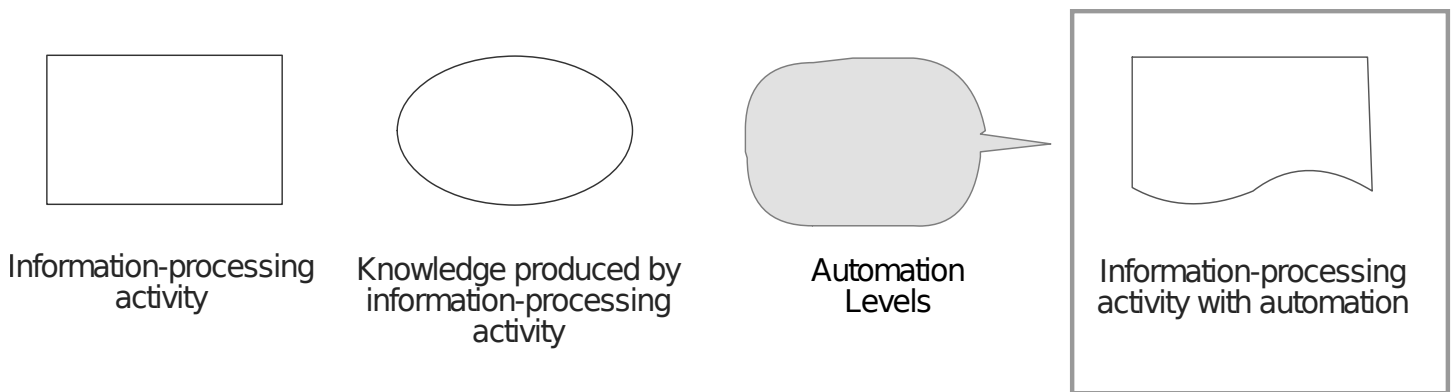


Figure 1: A legend for the decision ladder diagrams generated as part of the hCTA process. The practice innovation in the hCTA process for MAVIES was the identification of human information-processing activities aided by automation.

during insertion-extraction, and to determine a safe path back to base. During the *Return to Base* phase, the operator monitors the CUAV's safe travel home to end the mission, with the SUAVs again escorting the CUAV if necessary. Twenty-eight high-level tasks were specified at this stage, ordered temporally within their respective phases, and labeled "continuous" or "sequential."

Operational Event Flow

In the next step of the design process, an event flow diagram was generated, providing a finer level of specification of operator tasks that eventually produce a set of informational requirements for the user interface. The diagram is effectively a flowchart of the operator's execution of a task, and such a flowchart was created to represent each mission phase identified in the scenario task overview.

Process, decision and loop blocks in the event flow diagram are labeled with alphanumeric codes so that they can be cross-referenced throughout the rest of the hCTA process. The labels consist of a single letter (P for processes, D for decisions, L for loops) and a number. Ninety-one blocks were created in generating the event flow diagram for MAVIES. In addition to the 5 phases previously mentioned, there were also 3 continuous monitoring blocks, representing processes that must occur simultaneously throughout each of the 5 phases. Each continuous monitoring loop has a process that could interrupt the normal task flow in an emergent situation—such as a UAV being low on fuel. The 91 total blocks included 39 processes, 14 loops, and 20 decision blocks.

Decision Ladders

In order to determine what information is required for decisions, a structure called a *Decision Ladder* (Rasmussen, Pejtersen, & Goodstein, 1994) was generated for each complex decision-making process identified in the operational event flow.

Traditional decision ladders represent what information processes need to occur, independent of who will perform a

task or how a particular control task will be accomplished (Rasmussen, 1983). In the case of systems with computer-based decision support tools, the traditional decision ladder represents the information processing activities and states of knowledge that must be addressed by the tool whether or not a computer or a human makes the decision.

One advancement that this research effort makes over traditional decision ladders is recognizing that such complex decisions involving multiple unmanned aerial vehicles must leverage automation, at least at some level, to assist in the decision making process. To that end, in the decision ladders for this hCTA, we introduce a new information processing activity that is not agent independent.

In traditional decision ladders, an information-processing activity is represented by a rectangle, and resulting knowledge states in ovals (Figure 1). We propose that when a decision maker is faced with an information processing activity that requires optimizing several different variables, a task that is difficult for humans when faced with a large decision space and time pressure, this activity should be explicitly represented by a rectangle with a curved line (Figure 1). This shape indicates that a human will likely need some form of automation assistance due to the complexity of the information processing activity.

Figure 2 shows a cutout of the decision ladder for the decision "Is There a Suitable Initial/Alternative Route" and illustrates the decision ladder innovation in the application of the hCTA process for the MAVIES design. As part of the "Is There a Suitable Initial/Alternative Route" decision task, the operator supplies a set of constraints, such as the allowable proximity of hostiles and obstacles to the CUAV's path. These constraints will be used by the automation via an optimization process to evaluate the feasibility and safety of the possible routes.

With the help of an interactive visualization that allows the operator to rapidly conduct what-if analysis in changing constraints and variables of interest, the user processes information about the safety of routes and their efficiency in terms of fuel and flight time. This particular decision ladder is annotated with shaded blocks that suggest different possible Levels Of Automation (LOAs) (Sheridan & Verplank, 1978) that could be implemented as decision support for the information processing

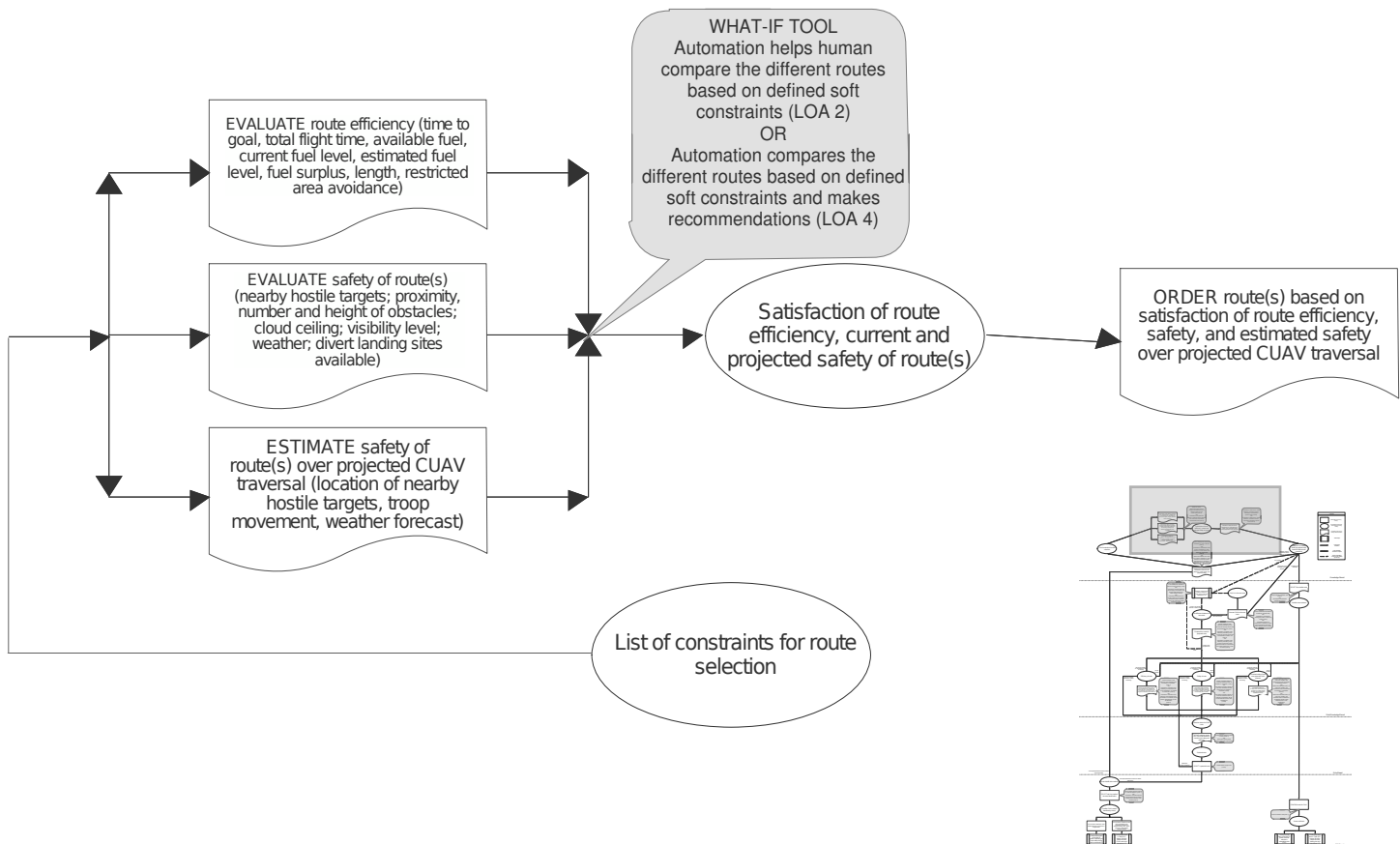


Figure 2: A cutout of the decision ladder for the for the complex decision named “Is There a Suitable Initial/Alternative Route?”

tasks. In this instance, a “what-if” tool aids the user at LOA2 (The computer offers a complete set of decision/action alternatives) by helping the human compare the different routes based on defined soft constraints. At LOA4 the automation suggests alternatives by comparing the different routes based on defined soft constraints and making recommendations. The decision as to which LOA or combination of LOAs to implement is left to the system designer.

Situation Awareness and Information Requirements

The next major step of the hCTA process is the derivation of Situation Awareness Requirements (SARs) from process blocks of the event flow that guide the designer in selecting elements for the user interface. Traditional formalizations structure Situation Awareness (SA) as the flow of information starting from human perception, through comprehension of the information, to the human projection into circumstances in the future (Endsley, 1995).

All three levels of SA are relevant to task execution blocks in the event flow. A set of 50 SARs spanning all operational phases were generated and traced through the perception-comprehension-projection levels of SA. This information, in combination with display information requirements from the decision ladder, was used to generate the interface.

Three of the SARs are given as an example in Table 3.

These are from the *En Route* phase of MAVIES and represent the operator’s SA for the time and distance for the CUAV to reach the landing site, whether or not the CUAV needs escort(s), and the possibility that the route could be compromised by hostiles, weather, or discovered obstacles. Each component of SA is labeled to associate it with one or more blocks in the operator event flow structure. For example, P9 means that this requirement is associated with Process 9 from the event flow and DL1 means the requirement came from the first decision ladder.

The combined requirements from the situation awareness and decision ladder analyses form the basis for information requirements for the actual display, detailed in the next section.

DISPLAY PROTOTYPE

The resulting MAVIES interface consists of two screens, a *Situation Awareness* display with major interface components for supervising the vehicles, and a *Health and Status* display for monitoring the health of the vehicles and the status of the mission (Figure 4). A prototype of the MAVIES user interface was implemented using the Qt cross-platform and application and UI framework (Nokia Corporation, 2012) in C++ on Windows platforms.

The interface is designed to accommodate both naturalistic and rational styles of decision making. Naturalistic decision making (Klein, 2008) emphasizes modeling how humans

Phase	SAR #	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
En Route	9	Visual feedback of positions of SUAV(s) while en route to the base (P7)	Position and movement of SUAV(s) (P7)	Estimated distance and time to reach the base (P7)
	10	Visual feedback of positions of SUAV(s) and CUAV while en route to landing site (P8)	Position and movement of CUAV and SUAV(s) (P8)	Estimated distance and time to reach the landing site (P8)
	11	Visual feedback of route safety (number of hostiles and movement, weather conditions, obstacles) during CUAV traversal (L3, P9)	Current route safe (P9, DL1) Current route compromised (P9, DL1)	Impact of the unsafe route on schedule (P11)

Figure 3: Situation awareness requirements from the *En Route* phase of MAVIES.

make decisions in complex, dynamic real-world environments. The MAVIES interface provides all available information to the user and permits them to either generate UAV routes and landing sites by hand or let the automation make such decisions for them. Operators can also use a mixture of both decision styles in that they can leverage the automation to make initial route suggestions, and then operators can modify them as they see fit to adjust for changing circumstances.

The Situation Awareness Display

The Situation Awareness display (Figure 4 left) was designed to provide geo-spatial SA with a zoomable map panel representing the mission environment. It shows the locations of the UAVs, target vehicles of low, medium and high priority of interest, and the UAVs' home base. The symbols for the UAVs and targets were chosen to conform to MIL-STD 2525 (US Department of Defense, 1999). The SA display also shows information related to the UAV routes of flight, landing areas and landing sites, and terrain information such as the location of obstacles and bodies of water.

The SA display has a panel at the top to indicate the current phase of the mission. The SA display allows the operator to select, examine and compare landing sites and routes for the CUAV with the help of the automation, which evaluates the safety of routes and landing sites. The automation indicates the results of the safety evaluation by coloring landing sites, paths and waypoints blue, yellow or red to indicate respectively that they are safe, that the safety cannot be determined, or that they are unsafe.

The user generates paths and landing sites for the UAVs either by hand or automatically, and can compare the plans over all of their characteristics using the two panels at the bottom of the display. The user may also adjust the criteria of what defines an acceptable or unacceptable landing site or route by setting the relative weights of characteristics in the automation's algorithm.

The Health and Status Display

The second display (Figure 4 right) provides vehicle health and status information to the user. It has a chat window and a panel representing the telemetry, video feeds, and relevant alerts for each UAV. These panels are assumed to be customizable depending on the exact types and configurations of the UAVs. The health and status screen also has a task timeline to indicate the planned tasks for each UAV, allowing the user to adhere to the mission schedule and perform landing, insertion and extraction at the appropriate times.

DISCUSSION

This paper described the application of cognitive task analysis techniques to design an innovative interface for the control of multiple heterogeneous UAVs in insertion-extraction missions. The hCTA process was used to generate information and functional requirements for the interface by creating a scenario task overview, an event flow diagram, a set of decision ladders, and situation awareness requirements.

The decision-making tasks that are performed in MAVIES, e.g., evaluating and ranking multiple UAV routes of travel based on various soft constraints for efficiency and safety, are made in a large, complex parameter space. In constructing the decision ladders for MAVIES, we recognized that it would be impractical for the human operator alone to solve these multi-variable optimization and constraint satisfaction problems; to even reach the trade space to make a decision, the human operator needs the automation to calculate and present optimal or satisficing solutions. Although traditionally decision ladders represent information processing activities and states of knowledge in a way that is agent agnostic, we were motivated to introduce a new decision ladder block type to represent information processing activities that require automation. This new block type can be used in combination with the "level of automation" block type

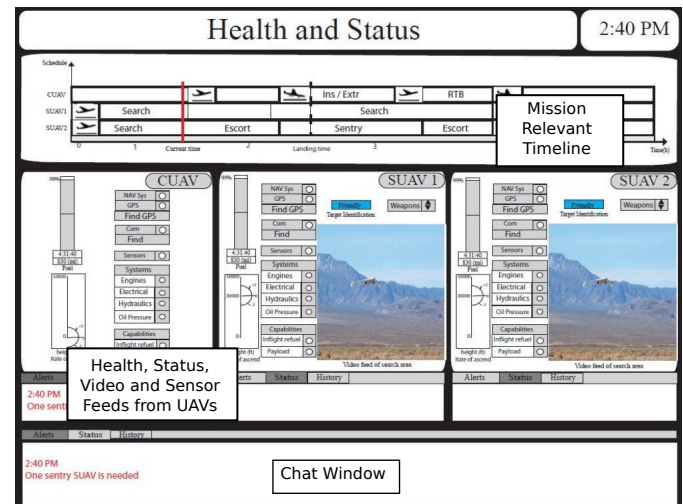
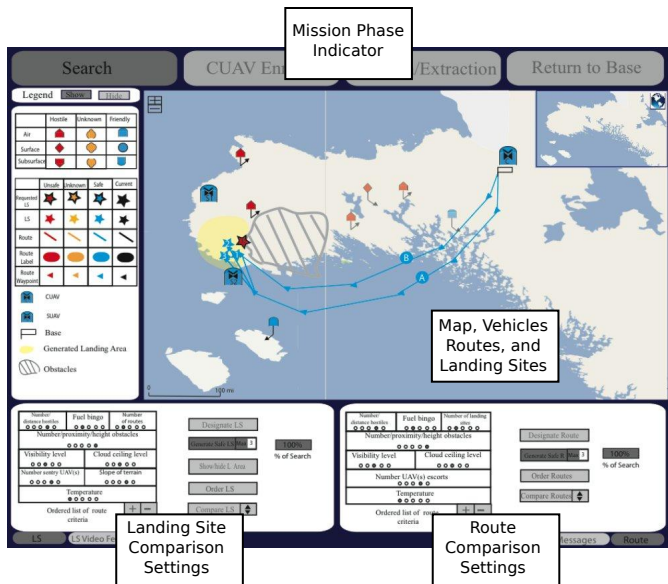


Figure 4: MAVIES screen shots. Left: *Situation Awareness* display. Right: *Health and Status* display

that indicates where automation is optional but not required.

The hCTA process is most useful when designing user interfaces in a team environment. It communicates requirements to the designers of algorithms and displays and provides traceability through multiple iterations of design, implementation and usability testing. This innovation enhances the decision ladders in their ability to convey that automation is required as an aid to humans when making decisions in a domain with difficult optimization tasks.

As a result of the hCTA efforts and the resulting MAVIES display, engineers are now working to design the algorithm to support this display. This Human Systems Engineering (HSE) approach is unusual, in that typically algorithm designers generate the optimization algorithm first, and then the interface designers are left to support the operator with often incomplete information because the interface requirements of the human were not considered at the time of algorithm generation. Future work will determine if this HSE approach is superior to a more traditional SE approach that does not consider human requirements early in the design process.

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