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# Multi-Autonomous Vehicle Insertion-Extraction System (MAVIES) Human Interface Design and Modeling

12/21/2011

**Abstract**

MAVIES (Multi-Autonomous Vehicle Insertion-Extraction System) is the culmination of a year-long multi-stakeholder effort between UTRC and the Humans and Automation Lab at MIT to design a human interface for insertion and extraction missions with multiple UAVs and optionally piloted rotorcraft. The design process is a successful application of the Hybrid Cognitive Task Analysis (hCTA) process that tracks dozens of tasks, decision-making processes and their associated situation awareness requirements to determine the proper allocation of responsibilities between the human operator and the automated mission planner.

This paper discusses the various accomplishments through several phases of a disciplined process of planning, analysis, design, implementation and testing of the human interface; this process included cognitive walkthroughs and interviews with helicopter pilots as subject matter experts as well as integration with automation systems and mission and vehicle simulation engines developed at UTRC. We also discuss ongoing novel efforts to model human operator mission performance and utilization when the operator simultaneously pilots their own vehicle and commands multiple "autonomous wingmen."

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# 1 Introduction

Current-day Unmanned Aerial Systems (UAS) realize the vision of the pilotless remote-controlled aircraft that observes and strikes targets at a great distance. However, the projected evolution of the operations of these systems is extending to missions where an Unmanned Aerial Vehicle (UAV) is able to land in a possibly hostile environment and insert or extract cargo or personnel. Additionally, high level control of UAS from a manned aircraft is expected to extend the range of these systems and improve operational teaming between manned and unmanned vehicles [1]. This work, a collaboration between the MIT Humans and Automation Laboratory and UTRC, focused on the development of a human operator interface for controlling multiple, heterogeneous UAVs in insertion and extraction missions.

The human user of the Multi-Autonomous Vehicle Insertion-Extraction System (MAVIES) is able to control 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. Examples of insertion-extraction missions include those where a friendly unit is in need of cargo resupply, or requires medical evacuation via the cargo vehicle from some location away from the base. The scout UAVs may be armed, in which case they can neutralize enemies on or near the CUAV's path or potential landing sites.

# 2 Human Interface Design Method

The human interface design of MAVIES was conducted through a number of phases:

- General mission analysis and information gathering
- Detailed analysis of tasks to be performed by the human operator
- Human interface requirements generation
- System design based on requirements

To generate situation awareness requirements for the 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. General mission analysis and information gathering sessions were performed at Sikorsky with Sikorsky test pilots as subject matter experts. Subsequently, the human interface was designed based on the input needs of each particular task and the situational awareness requirements of that task.

# 3 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, hybrid cognitive task analysis extends well-worn cognitive task analysis methods to generate information and display 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. Generate situation awareness requirements
4. Create decision ladders for critical decisions

The hCTA method has previously been used to generate functional and interface requirements for the supervisory control of multiple, heterogeneous unmanned vehicles, and for the development of an interactive in-cab scheduling interface for railroad locomotive operators [14].

## 3.1 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 uses the scout UAVs to determine a safe path and landing site for the cargo UAV. Then the cargo UAV takes off, beginning the *En Route* phase, where the user monitors the CUAV's progression to the landing site. During *Insertion-Extraction*, the CUAV lands at the designated site, performs the on-loading and/or off-loading objective of the mission, and subsequently takes off. During the *Return to Base* phase, the operator monitors the CUAV's safe travel home to end the mission. 28 high-level tasks were specified at this stage, ordered temporally within their respective phases, and labeled "continuous" or "sequential."

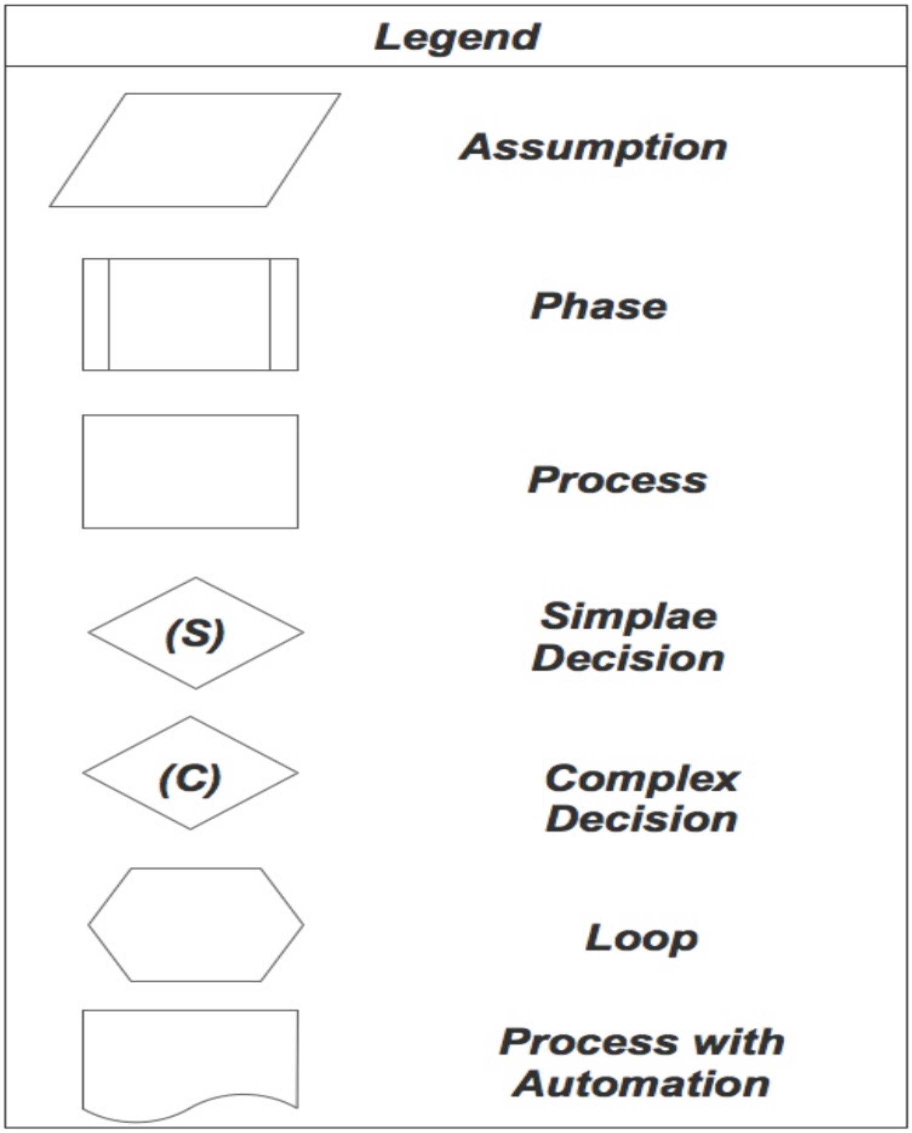


Figure 1: The event flow diagram symbology.

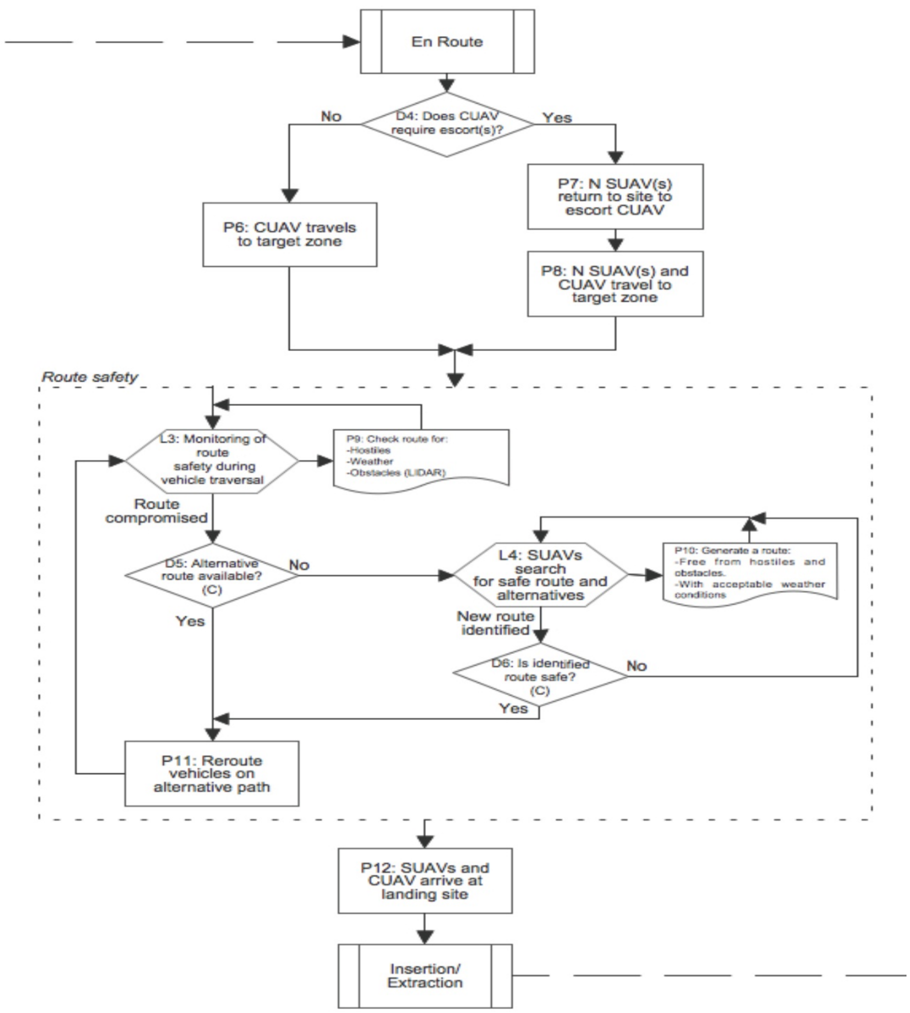


Figure 2: An example section from the event flow diagram for the *En Route* phase of the mission.

## 3.2 Operational Event Flow

In the next step of the design process, an event flow diagram was generated, providing a much a finer level of specification of operator tasks that would eventually help to produce a set of informational requirements for the user interface. The event flow diagrams for MAVIES are in Appendix A of this document. An event flow diagram, effectively a flowchart program of the operator's execution of a task, was created for each phase of the scenario task overview. Symbol types for blocks in the diagram represent:

1. Assumptions or conditions to be met prior to the start of a phase
2. The commencement and termination of phases and transitions between phases
3. Operator processes
4. Operator processes requiring collaboration with automation
5. Simple decisions
6. Complex decisions
7. Loops and iterative execution
8. Arrows for flow of operator execution

The event flow diagram symbology is given in Figure 1. Process, decision and loop blocks 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. 91 blocks were created in generating the event flow diagram. The flow diagram was grouped into 8 sections: one section for each of the 5 phases, and, separately, 3 sections representing continuous monitoring loops. 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.

An example of the event flow is shown in Figure 2. In this segment, the operator decides if the CUAV requires that the SUAVs escort it on its way to the landing site, and acts accordingly. Then the operator performs the *Route Safety* monitoring loop, checking the route for hostiles, weather problems, and obstacles with the help of the automation. If the route is compromised, another loop process searches for safe alternatives, and reroutes the vehicles on an alternate path. Once the CUAV arrives at the landing site, the insertion-extraction phase of the mission begins.

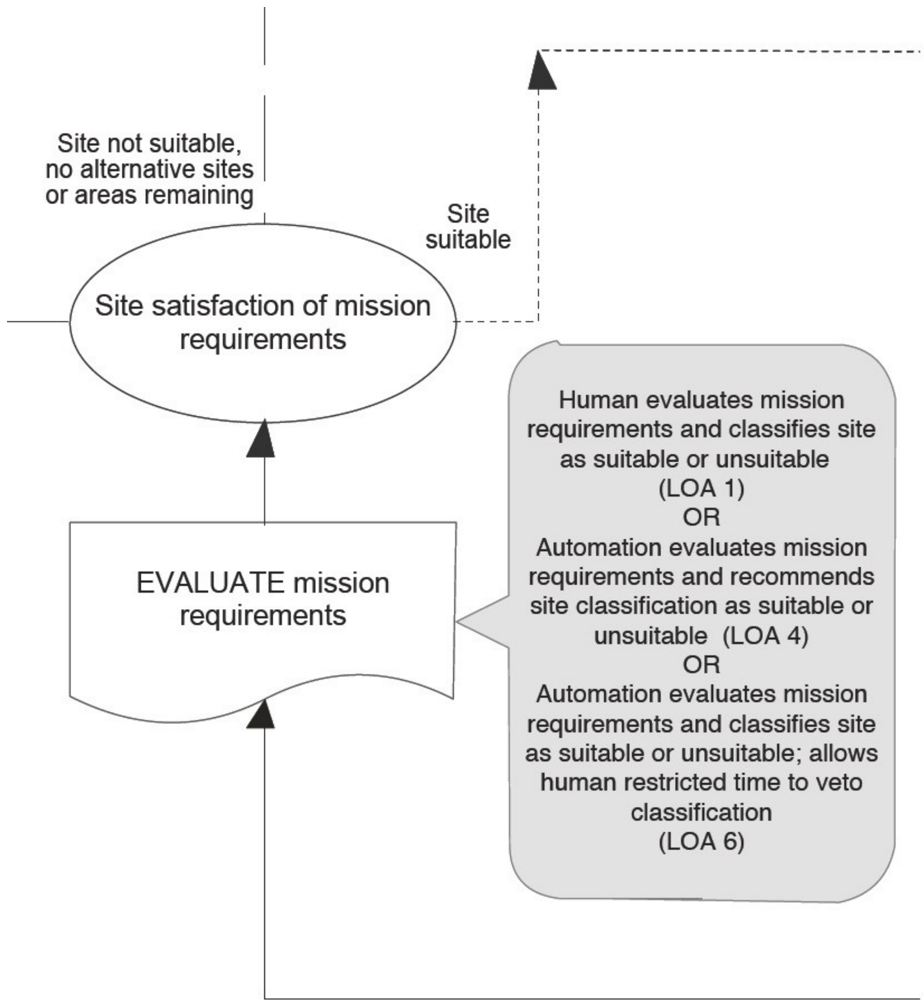


Figure 3: An example MAVIES decision ladder.

| SAR Number | SAR Level | Description |
|---|---|---|
| 7 | Perception | Visual and auditory feedback of number of escorts needed by CUAV (D4) |
| | Comprehension | CUAV needs or doesn't need escorts (D4) |
| | Projection | Changes in schedule according to the new SUAV assignment (D4) |
| 8 | Perception | Visual feedback of position of CUAV while en route to landing site (P6) |
| | Comprehension | Position and movement of CUAV (P6) |
| | Projection | Estimated distance and time to reach the landing site (P6) |
| 11 | Perception | Visual feedback of route safety (number of hostiles and movement, weather conditions, obstacles) during CUAV traversal (L3, P9) |
| | Comprehension | Current route safe or current route compromised (P9, DL1) |
| | Projection | If route compromised, impact of the unsafe route on schedule (P11) |

Table 1: Three example situation awareness requirements for the *En Route* phase of MAVIES.

## 3.3 Decision Ladders

In order to determine what difficult tasks may have performance benefits with the advent of automation, a structure called a *Decision Ladder* [17] was generated for each complex decision-making process identified in the operational event flow. Decision ladders map the decision making process as it proceeds from lower to higher levels of information processing and decision making. Specifically, each decision making process block is identified to represent one of three types of decision related behaviors; these are, in order from lowest to highest, skill-based behavior, rule-based behavior, and knowledge-based behavior. The complete decision ladders for MAVIES are in Appendix B of this document.

For the MAVIES design, decision ladders were generated for the complex decisions named "Is There a Suitable Initial/Alternative Route," and "Is Identified Site Safe." Figure 3 shows a small part of the decision ladder for the latter. This particular decision ladder is annotated with shaded blocks that suggest functionality for different levels of automation that would be implemented as decision support for the user.

### 3.4 Situation Awareness and Information Requirements

The hallmark of the hCTA process is the derivation of Situation Awareness Requirements (SARs) from 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 [7]. The situation awareness requirements derived for MAVIES are in Appendix C of this document.

All three of these levels of SA are relevant to task execution blocks in the event flow. A set of 50 SARs were generated and traced through the perception-comprehension-projection levels of SA, and each was listed with labels of one or more process blocks for which it was needed by the operator. This information, in combination with the operational event flow, was used to generate the interface.

Three of the SARs are given as an example in Table 1. These are for 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.

## 4 The MAVIES Human Interface

The MAVIES human interface was designed to work on dual visual displays, and consists of two screens, a *Situation Awareness* display with major interface components for controlling the vehicles, and a *Health and Status* display for monitoring the health of the vehicles and the status of the mission. A set of interface design storyboards (which were also used to perform a cognitive walkthrough exercise with test pilots at Sikorsky) are given in Appendix D.

The interface is designed to accommodate both naturalistic and rational styles of decision making. Naturalistic decision making [10] emphasizes modeling how humans make decisions in complex, dynamic real-world environments. A more rational decision making process proceeds with the aid of automation. The MAVIES interface facilitates both naturalistic and rational decision-making in the mission environment by providing all available information to the user and permitting them to either generate UAV routes and landing sites by hand or let the automation make such decisions for them.

### 4.1 The Situation Awareness Display

The Situation Awareness display is shown in Figure 4. It provides 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 [4]. The SA display also shows information

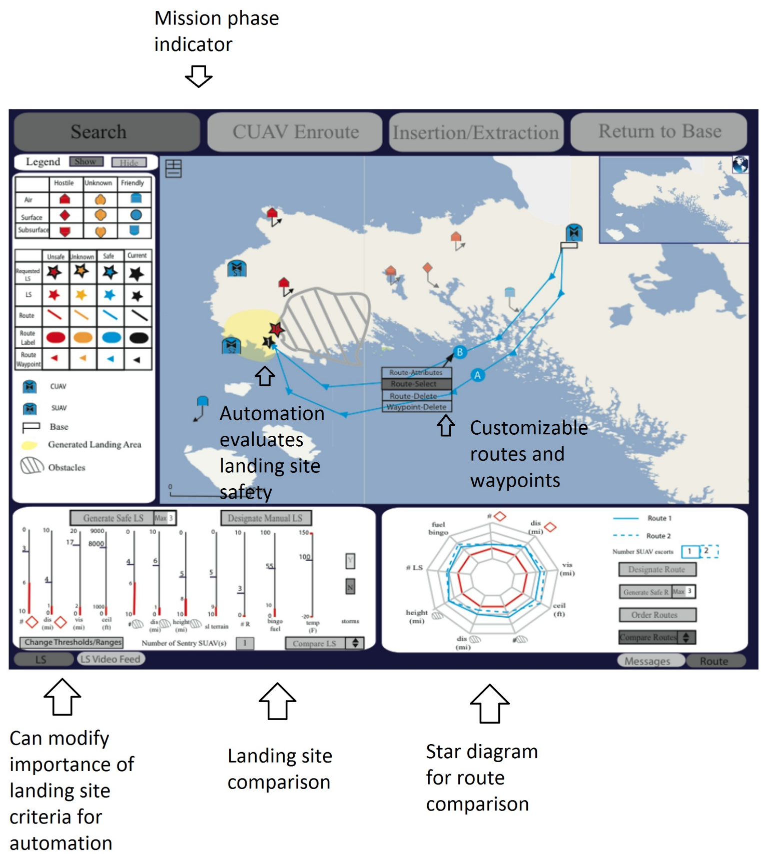


Figure 4: The MAVIES Situation Awareness Display.

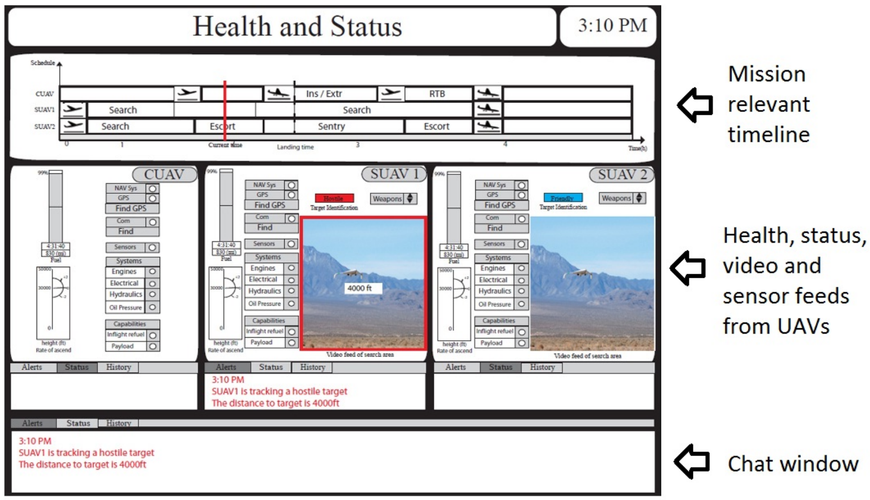


Figure 5: The MAVIES Health and Status Display.

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.

## 4.2 The Health and Status Display

The second display, which provides health and status information to the user, is shown in Figure 5. It has 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.

## 4.3 Usability Evaluation

On November 4th, 2011, our team visited Sikorsky Aircraft in Stratford, Connecticut, to conduct interviews and other exercises with rotorcraft test pilots as subject matter experts. The two test pilots are part of Sikorsky's engineering department and collectively have many years of experience flying helicopters in the US Army and the Australian Air Force.

A cognitive walkthrough was performed with the pilots as a method to evaluate the usability of the MAVIES interface. In this instance we chose the task of selecting and evaluating a landing site and instructed the pilots to speak out loud about their thought processes while completing this task with MAVIES. Storyboard images of the situation awareness display were shown to the pilots as a stand-in for a working prototype. Audio recordings were made of the discussion.

One major consideration that was raised as part of the exercise was the overwhelming importance of aircraft performance limits to the pilot's situation awareness. Poor planning in relation to performance and power is a common contributing factor to rotorcraft accidents, where typically the helicopter collides with the ground or with obstacles during a takeoff, an approach to hover, a landing, or other maneuvers at low altitude. In insertion-extraction missions, it is important for the operator to know the weight, and thus the available power, of the aircraft before and after loading or unloading at the landing site.

Performance factors such as power margin and rate-of-climb of the rotorcraft will affect landing site selection in conjunction with others—for example, the presence of obstacles or other hazards in the vicinity of the landing site. As a future improvement to the MAVIES interface, we may designate a landing site parameter that is a function of power margin, obstacle distance, slope and other factors that can aid the operator situation awareness about the safety of the site. We have also considered designing a separate screen with controls and visualizations devoted to better situation awareness of aircraft performance factors as they pertain to the insertion-extraction mission.

## 4.4 MAVIES Implementation

A prototype of the MAVIES user interface was implemented using the Qt cross-platform and application and UI framework [16] in C++ on Windows platforms. At the time of this writing, implementation of parts of the situation awareness display—specifically UAS base creation, target vehicle creation, landing site creation, and landing site comparison via a star diagram—are complete. The health and status screen is currently implemented as a mock-up. What follows is an explanation of the software construction and what classes of Qt were used.

The application begins simply by initializing the application window, several images and labels, and layout classes. There are two layout types used: QVBoxLayout and QHBoxLayout. QVBoxLayout lays out the items added to it vertically, and QHBoxLayout does so horizontally; these layouts are stacked to get the overall layout for the situational awareness window. The method

QObject::connect is for event handling; it links a certain action to a certain event (for instance, right-clicking the map to displaying the context menu).

The three classes, LandingSite, UAV and ForeignCraft are very similar. A future design consideration should be to make a superclass called "VehicleIcon" containing the common functionality of these three classes, and subclass it accordingly. One issue to consider when using Qt is that these classes subclass from QGraphicsItem. Many features of Qt only work for subclasses of QObject or its subclass QWidget. QGraphicsItem is not a subclass of these, and is treated very distinctly. We may consider using multiple inheritance, letting the VehicleIcon class inherit both QGraphicsItem (allowing for simple graphical functionality) and QObject, but we note that multiple inheritance is difficult with QObject, due to the way the Qt library parses this particular class (subclassing from QObject requires one do many special things for MOC to work properly). As an example, Qt has animation capabilities, but only for subclasses of QObject. The animation for the UAVs Launch feature was implemented by hand. However, we feel that multiple inheritance should be considered in the long run.

For several reasons, we need to keep a list of all instances of each of these classes (i.e. a list of all the LandingSite instances). This is useful because it allows other classes, such as the context menu CustomContext class, to manipulate the LandingSite instances. Ultimately we decided to implement this as a global variable. The classes have static methods which return this list of pointers to instances.

QGraphicsScene was subclassed twice to make LSGraphicsScene and RSGraphicsScene. These are the landing site selection and comparison screens, respectively. This allows for basic event handling, such as clicking the LSGraphicsScene to update one of the landing site criteria, or to update the graphical display of the landing sites criteria in the RSGraphicsScene display.

# 5 Operator Modeling

The aim of the MAVIES operator modeling effort is to provide an alternative to human-in-the-loop experiments for evaluating design choices that can affect human performance in supervising unmanned vehicles while flying an optionally piloted vehicle. It is assumed that the optionally piloted vehicle has all the controls that a regular aircraft would have and is capable of flying on autopilot if needed. The unmanned vehicles are assumed to have enough autonomy to take off, land, and move from one location to another autonomously. Certain unmanned vehicles can also be armed and can fire missiles. The unmanned vehicles are controlled via a point-and-click interface. Mission-related information can be communicated to the command center using a keyboard. A high level representation of the model is provided in Figure 6.

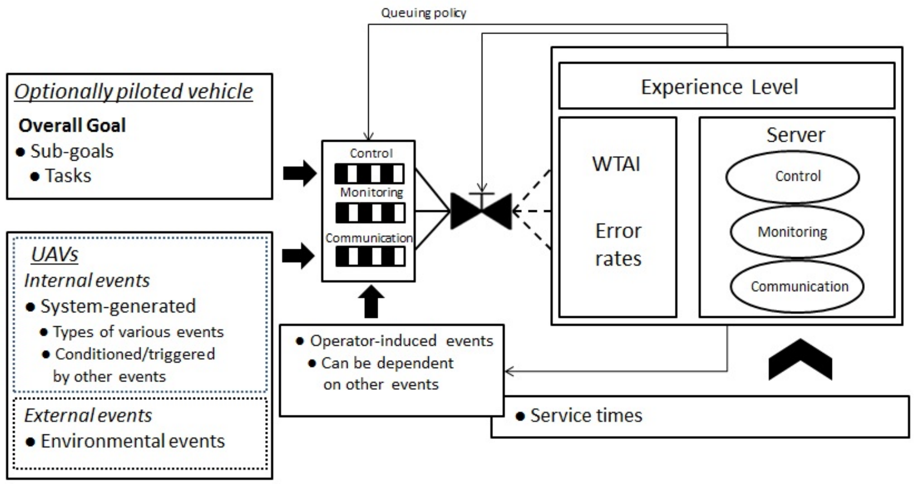


Figure 6: A high level representation of the operator model.


Figure 7: The optionally piloted vehicle component of the operator model.

## 5.1 Discrete Event Simulation

The modeling technique utilized in this work is that of queuing-based discrete event simulation (DES). DES models a system as it evolves over time by a representation of events. Human supervisory control of unmanned vehicles has a complex, time critical, event-driven nature, which makes DES models appropriate for modeling in these settings. Queuing-based DES models have also been used in the past to evaluate pilots visual behavior when flying a jet airplane [2]. In other studies, queuing models have been used to evaluate the security and efficiency of air traffic control systems or flight management tasks [3] [18]. In the next sections, various constructs of the DES model are presented and discussed.

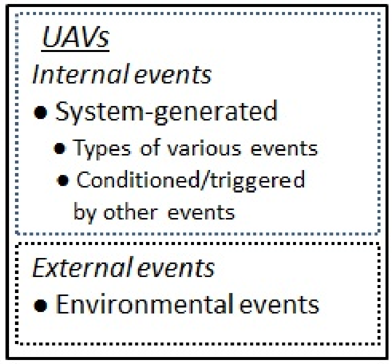


Figure 8: The Unmanned Aerial Systems component of the operator model.

## 5.2 Operator Model for Optionally Piloted Vehicle

The Optionally Piloted Vehicle (OPV) component of the model is given in Figure 7. The overall goal of the pilot is decomposed into sub-goals, which in turn can be broken down into various tasks. This architecture is similar to Deutsch's D-OMAR model for examining flight deck technology [5].

Cognitive Task Analysis (CTA) can be used to gather information about different tasks that need to be completed to accomplish a certain (sub)goal. In the past, several studies have analyzed tasks that pilots complete during various phases of a flight, such as approach and landing [8] [9]. One study even provides a detailed analysis for a flight from Los Angeles to New York [11]. However, in all these studies the time required to complete various tasks is not specified (or is estimated roughly), which can be problematic, since accurate task completion times (service times) are essential for having accurate DES models. One way to alleviate this problem is to gather detailed data using a flight simulator.

## 5.3 Unmanned Aircraft System

The Unmanned Aircraft System (UAS) component of the model is given in Figure 8. Internal events arise due to the nature of the mission and vehicle capability. An example of an internal event is a replanning of vehicle task assignments to ensure that the tasks that the operator wants to complete are allocated to the vehicles. Such an event should be expected by both the operators of unmanned vehicles and designers of the system. It is also important to note that events can be triggered by other events, and that some events can disrupt the regular flow of events (for example, a certain event needs to be serviced before any other event can be serviced). For instance, finding a hostile target can trigger an event asking the operator to approve destruction of this target. Environmental events are external to the system and arise due to unpredictability of the environment. Events like these, such as an emergent threat area or a meteorological condition, create the need for operator interaction.

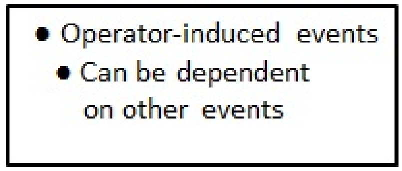


Figure 9: The operator-induced events module of the model.

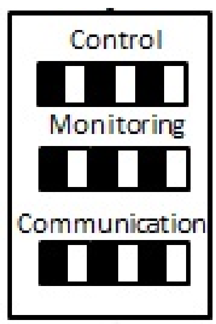


Figure 10: The queuing component of the operator model.

## 5.4 Operator Induced Events

Operator-induced events address the ability of the human to intervene at any point and create additional tasks or re-plan, if desired. This can occur if the operator modifies an existing plan (replanning) with the expectation that the intervention will lead to improved performance. The operator can also task the vehicle to search a specific area if he/she thinks that the automation is doing a suboptimal job in searching that specific area. Although both vehicle-generated and operator induced events are internal to the system, the former are pushed on to the operator by the system, whereas the latter are generated by the operator. Similar to the system-generated events, operator generated events can also trigger and be dependent on other events. The operator induced events module of the model is shown in Figure 9.

## 5.5 Queue

The queue consists of three parallel sub-queues, based on Wickens' multiple resource theory [21]. More specifically, each sub-queue stores a different type of event. The three types are control, monitoring, and communication, which correspond to the aviate, navigate, and communicate task breakdown used in aviation domains. The queues are populated simultaneously by events from the optionally piloted aircraft and UAS system. The queuing policy defines the order by which the events that are waiting in the queue are serviced and can be varied to capture operator task switching strategies

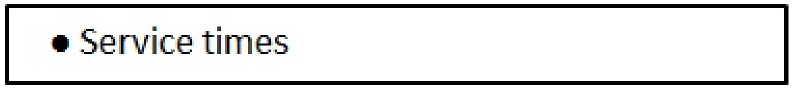


Figure 11: The service times component of the operator model.

There are various queuing policies that can be implemented in a DES model. Some examples of policies include first-in-first-out (FIFO), last-in-first-out (LIFO), shortest service time first, and highest attribute first, among many others. The FIFO, LIFO, and shortest service time first queuing policies are self-explanatory. The highest attribute first represents a policy in which the high priority events are serviced first [15], and priorities of the events can be determined by the designer of the model.

A queuing policy that includes a combination of several policies can also be implemented. The within-queue queuing policy defines the order by which the events that are waiting in the queue are serviced and can be varied to capture operator task switching strategies. Various within-queue queuing policies can be implemented in a DES model. We suggest using a priority based within queue queuing policy, where priority levels of the events can be determined by the designer of the model based on the mission scenario, task types and (if available) historical data sets. The between-queue queuing policy defines the order by which different event types are attended. Based on the aviate navigate communicate task priorities, we suggest assigning priority levels to the three sub-queues, i.e., when choosing between control, monitoring, and communication tasks of the same priority level, the pilot will choose to service the control task, followed by monitoring and communication tasks.

More specifically, each sub-queue can have a priority coefficient that will be multiplied by the priority level of the tasks of the appropriate sub-queue, and the task with the highest priority level will be serviced first. This type of task priority structure could ensure that high priority communication (or monitoring) tasks do not wait in the queue for the completion of low priority control or monitoring tasks. The priority coefficients of sub-queues can be calibrated using data from pilot tests. Furthermore, some events in the queue might be dependent, i.e., servicing one event will require the dependent event to be serviced as well. It is possible that events across different sub-queues can be dependent as well. For example, in a certain situation it might be required to communicate with a command center and simultaneously control the aircraft.

### 5.6 Service Processes

Service times represent the time that the operator is required to interact with an event. The service times module of the model is shown in Figure 11. The service times can be uniform or of random nature. In the latter case, they are usually characterized by a probability distribution function. Each event type can have its associated service distribution, which captures the variability of a single

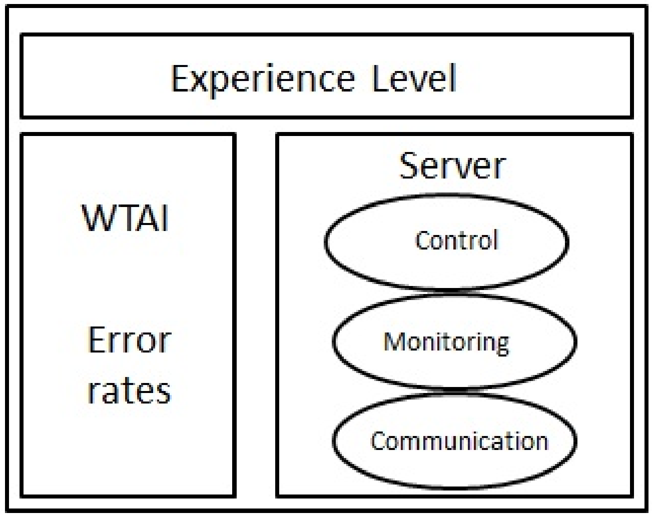


Figure 12: The human operator component of the operator model.

operator servicing tasks, as well as variability between operators. Occasionally, service distributions are non-stationary and can change over time. To account for the change in service times over time, the parameters describing the service time distribution can be varied over time. Furthermore, if the variability of service times over time is so large that it cannot be accounted for using the same service distribution, another service distribution can be utilized to accurately characterize the variation of service times.

Servicing an event can have a further impact on the state of the system. First, it can unblock other events, and, secondly, it can trigger other events. Not servicing an event can also have a profound impact on the system, since some of the events that are not serviced expire and leave the system without being serviced. This can lower the efficiency and performance of any system. It is also possible that an unserviced event can stay in the system and dramatically increase the number of events waiting to be serviced.

## 5.7 Human Operator

The human operator is represented by various constructs shown in Figure 12. More specifically, experience level, wait times due to attention inefficiencies (WTAI), operator error rates, and event servers represent the human operator. The concept of wait times due to attention inefficiencies (WTAI) has been previously used to model the performance of UV operators [6] [13]. WTAI represents the effects of low situation awareness on task wait times. Previously, it has been used in conjunction with the busyness level of operators to account for additional delays in servicing events [12]. More specifically, it was assumed that the wait time is the greatest when the operator is either very busy or is almost idle. The wait time is the shortest when the operator is moderately busy. The WTAI concept can be used in the new model in conjunction with the level of experience of operators. Specifically, the dependency between the wait time and utilization will change based on the operator experience level.

## 5.8 Error Rates

Operator error rates are also taken into account. Specifically, according to the action classification of errors, omission and commission errors are considered. During an omission error, the event is delayed until it expires or an event of the same type is created. During a commission error, the wrong action is taken. In the model, omission errors are taken into account by the fact that some events expire if they stay in the queue longer than a predetermined amount of time. Also, events might stay in the queue until the end of the mission without being serviced. WTAI and inefficient queuing policies can contribute to omission errors, since servicing only one type of event for a prolonged period might cause other types of events to time out. Also, WTAI can introduce additional delays, which might result in event time-outs.

Commission errors account for events that are serviced but with the wrong outcome. Commission error rates can be found from previous HAL studies. Also, data from US military unmanned vehicle mishaps and US naval aviation post-accident data can be used to extract information about commission error rates. However, the reported commission error rates represent average values for a given period and do not take into account pilot experience, which is likely to have a significant impact on the error rates. Operators' attention inefficiencies also influence commission error rates, hence, we propose to use the WTAI value as a multiplier in determining commission error rate, i.e., $P(error) = \alpha \cdot WTAI$, where $\alpha$ is a normalizing factor taking into account the average error rate that can be found from the literature. This definition of commission error rates also takes into account pilot experience, since WTAI curves vary for different levels of experience.

## 5.9 Multi-tasking

To account for multi-tasking abilities of the human operator, each type of task has an associated demand level, which is assigned by the experimenter / model designer. This is similar to Wickens' attempt to model dual-task performance by assigning a demand value for each information processing stage for different tasks and calculating dual-task interference values. The way to best represent multitasking in the model is still under investigation.

Operator inefficient task switching can contribute to lowered performance. For example, the operator can overly concentrate on servicing one type of task (e.g., control tasks) and ignore servicing other tasks for some period (cognitive lockup), even though the demand threshold hasn't been reached. Alternatively, the operator can choose to service the task with lower priority, ignoring the high priority task. To account for inefficient switching (which depends on operator experience and level of attention inefficiencies), inefficient switching probability can be used in combination with the WTAI value, e.g., $P(sw_{error}) = \gamma \cdot WTAI$, where $\gamma$ is a normalizing constant coefficient. $P(sw_{error})$ represents the probability of not switching according to the priority levels (as described above).

## 5.10 Task-based Versus Vehicle-based UAV Control

In modeling task-based versus vehicle-based control, the arrival rate probability density functions, as well as service time distributions can be significantly different. More specifically, the nature of tasks that operators perform is different. For example, in vehicle-based control, operators are required to control the vehicles to direct them to the required locations. Occasionally, operators might be required to direct the vehicles away from threat areas and closer to the area that needs to be searched. Also, various characteristics (e.g., speed, endurance, maneuverability, etc.) of different unmanned vehicles might require operators to interact with vehicles more or less. Increasing the number and heterogeneity of vehicles can quickly overload the operator, since each individual vehicle needs to be controlled by the operator.

In a system with a task-based architecture, the operator does not directly control the vehicles and, generally, is not concerned with the speed, endurance, or other characteristics of the vehicles. The operator supervises the tasks that need to be accomplished, which, in turn, dictate the behavior of the vehicles. Thus, increasing the number or heterogeneity of vehicles in a task-based architecture should not increase the operator's workload, unless the additional vehicles make it easier and faster to find additional targets, which require operator assistance. However, even if operator workload increases, it should increase much less compared to the vehicle-based control scenario.

To conclude, the main differences between modeling task-based and vehicle-based control scenarios are input probability distribution functions that describe various event arrival rates and service times. Also, dependencies of tasks on other tasks will be different. At the same time, the level of attention resources required to complete the tasks in a vehicle-based scheme might be different from the resources required in a task-based scheme. More work still needs to be done to use the level of centralization/decentralization as a parameter in the model. However, it is clear that using such a parameter is contingent upon having excellent knowledge about the differences of task-based and vehicle-based control for a specific interface.

One way it might be possible to take the level of task-based and vehicle-based control into account in a DES model is to convert task-based events into vehicle-based events. More specifically, if the probability distribution functions of event arrivals are given for a task-based system, these event arrivals can be converted to vehicle based event arrivals, with different arrival rates and, potentially, different service times. For example, an arrival of a search task creation event in a task-based control system might be equivalent to the arrival of multiple events setting a vehicle's next location in a vehicle-based control system.

## 5.11 DES Model Inputs and Outputs

### 5.11.1 Inputs

- Probability density functions of system-generated events
- Probability density functions of operator-generated events
- Probability density functions of environmental events
- Probability density functions of service time distributions
- Queuing policies
- Dependencies between tasks
- A categorization of tasks into communication, motor, and monitoring task types
- Attention resources required to perform each type of task
- Operator error rates

Probability density functions of arrival rates and services times for the unmanned aircraft system can be extracted from previously conducted studies which are being modeled. For the optionally piloted aircraft, CTA can be used to gather task arrival times. The queuing policy that operators utilize can be extracted from previous experiments and implemented in the model. Also, the queuing policy can be changed to evaluate the impact on system performance. The dependency between tasks can be modeled for each mission scenario by knowing how the actual system operates. Categorization of tasks based on motor, monitoring, and communication tasks correspond to aviate, navigate, and communicate task classification in aviation domain. Hence, this categorization can be found from previous studies.

For the unmanned vehicle system, the designer of the model can indicate task categories. However, it should be mentioned that a majority of the interfaces for unmanned vehicles only have tasks that correspond to the motor classification, since operators need to point and click to command the vehicles, and communication with the command center is usually established via chat messages. The level of attention resources required to service each type of task can be estimated by the designer of the system, in consultation with pilots.

Operator omission and commission error rates will be estimated as a range of possible outcomes linked to workload and attention inefficiencies. The data from US military unmanned vehicle mishaps can also be used extract information about the rate of operator error [20]. US naval aviation post-accident data analysis can also be used as a source of pilot error rates [19].

### 5.11.2 Outputs, DES-Based Metrics

- Utilization
  - Average utilization
  - Utilization calculated for 1 min, 5 min, 10 min intervals (or any other interval)
- Event wait time in the queue
  - Average event wait time in the queue
  - Maximum event wait time in the queue
  - Wait time for specific types of events can also be measured
- Event time-out rate
  - Overall time out rate
  - Time out rate for specific types of events
- Number of tasks completed
  - Number of overall tasks completed
  - Number of specific tasks completed

## 5.12 Mission-specific Metrics

Mission-specific metrics are designed to capture the performance of operators during a specific mission environment. For example, when the mission requires identification of friendly or hostile targets, a mission-specific metric can be the percentage of correct identifications. In another example, when an operator needs to destroy enemy targets, a mission specific metric can be the correct and timely destruction of the targets.

All of the DES-based metrics can be extracted from the queue and the server. More specifically, average utilization and peak utilization are output directly from the server. These metrics are influenced by the input probability distribution functions, as well as inter-dependencies between tasks. The level of attention resources required for different tasks will also influence utilization level. The number of tasks serviced is also directly output by the server. As previously mentioned, arrival rate distributions of events as well as dependencies between events will influence the number of tasks that are serviced. Event types as well as service time distributions also influence the number of serviced tasks.

Event wait time values can be extracted from the queue. The queuing policy and operators' multitasking abilities will influence wait times. Arrival rate distributions and service time distributions will also affect wait times. These factors also influence event time out rates, which can be obtained from the queue.

# Appendix A: Event Flow Diagrams

Figures 13, 14, 15 and 16 show the event flow diagrams for the four mission phases of MAVIES. Figures 17, 18, 19, and 20 show event flow diagrams for five additional continuous monitoring tasks that we analyzed as part of the MAVIES event flow.

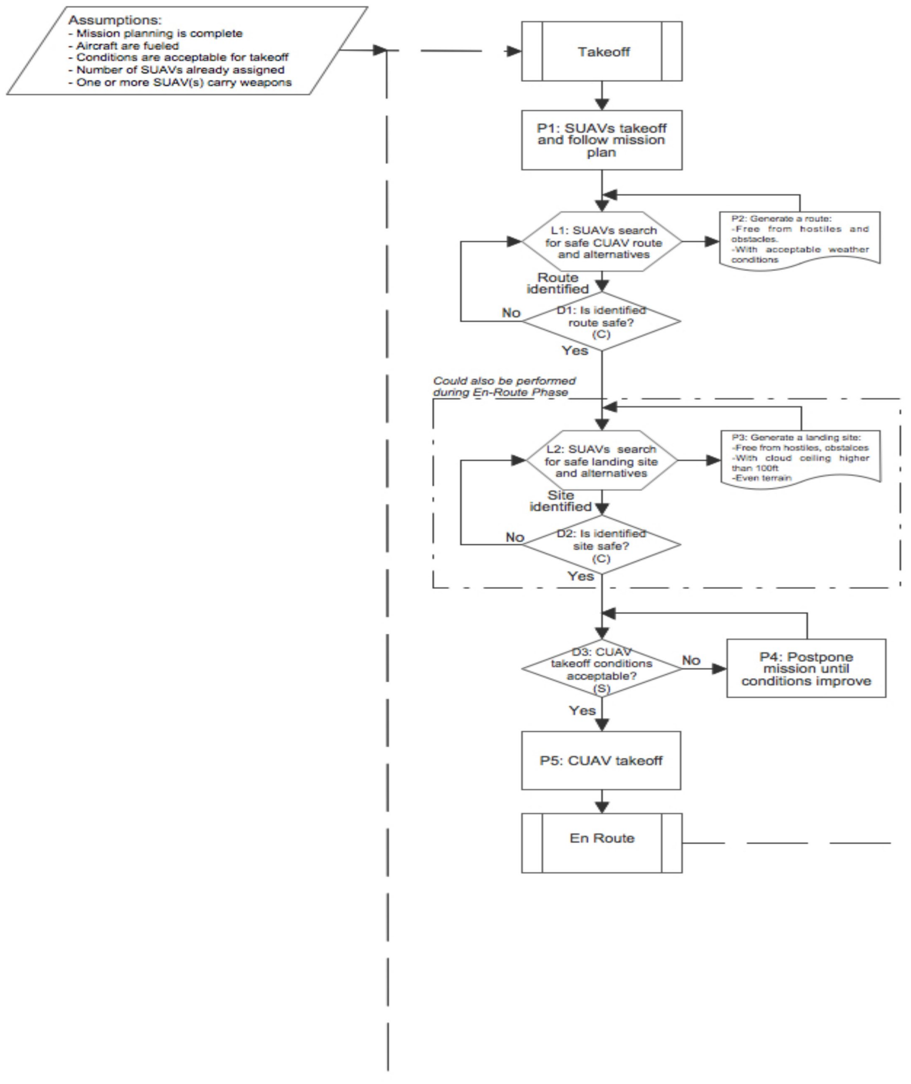


Figure 13: Event flow diagram for the *Takeoff* phase

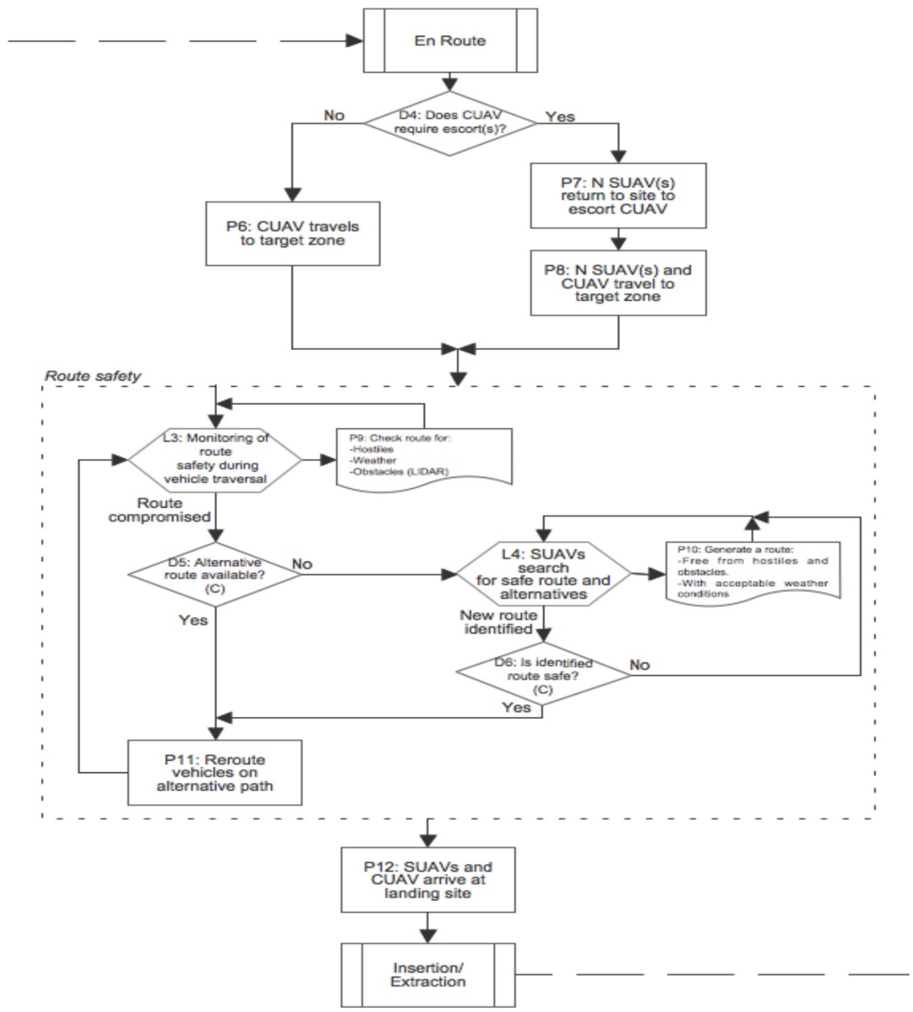


Figure 14: Event flow diagram for the *En Route* phase of the mission.

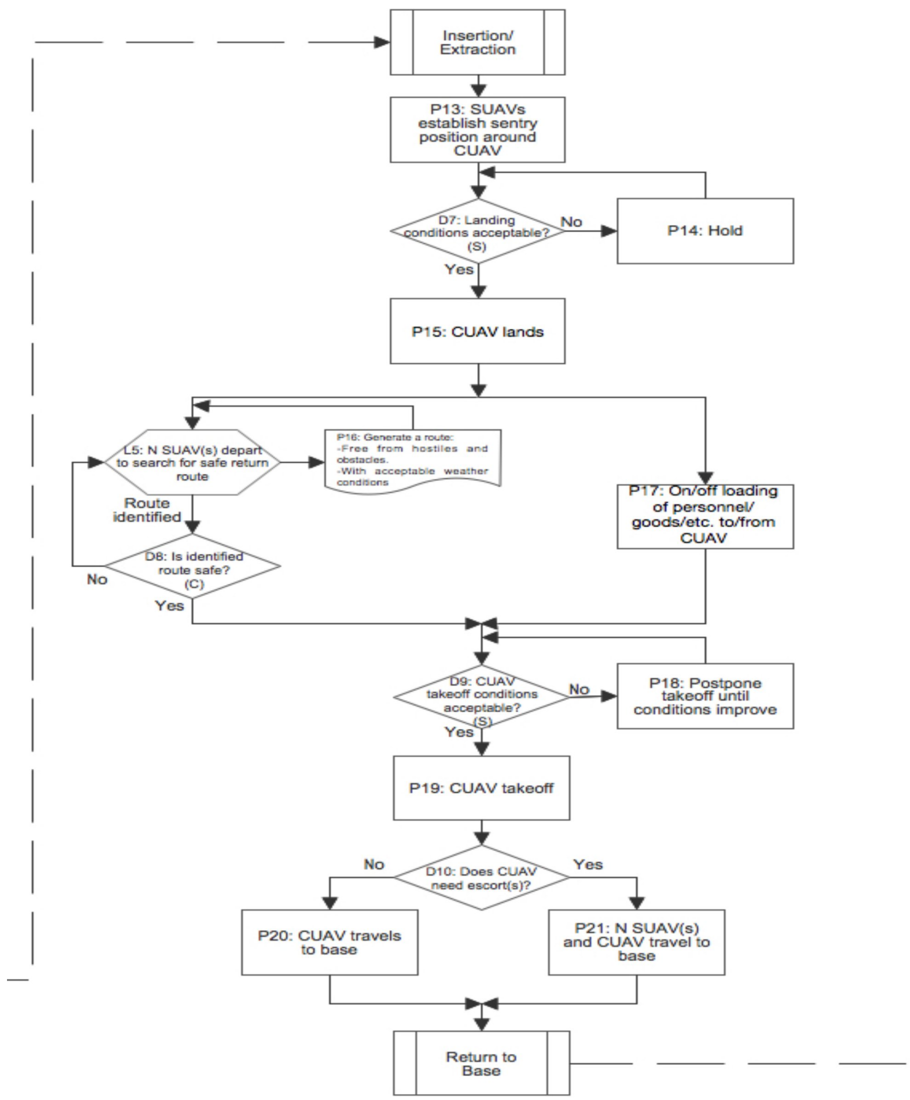


Figure 15: Event flow diagram for the *Insertion Extraction* phase

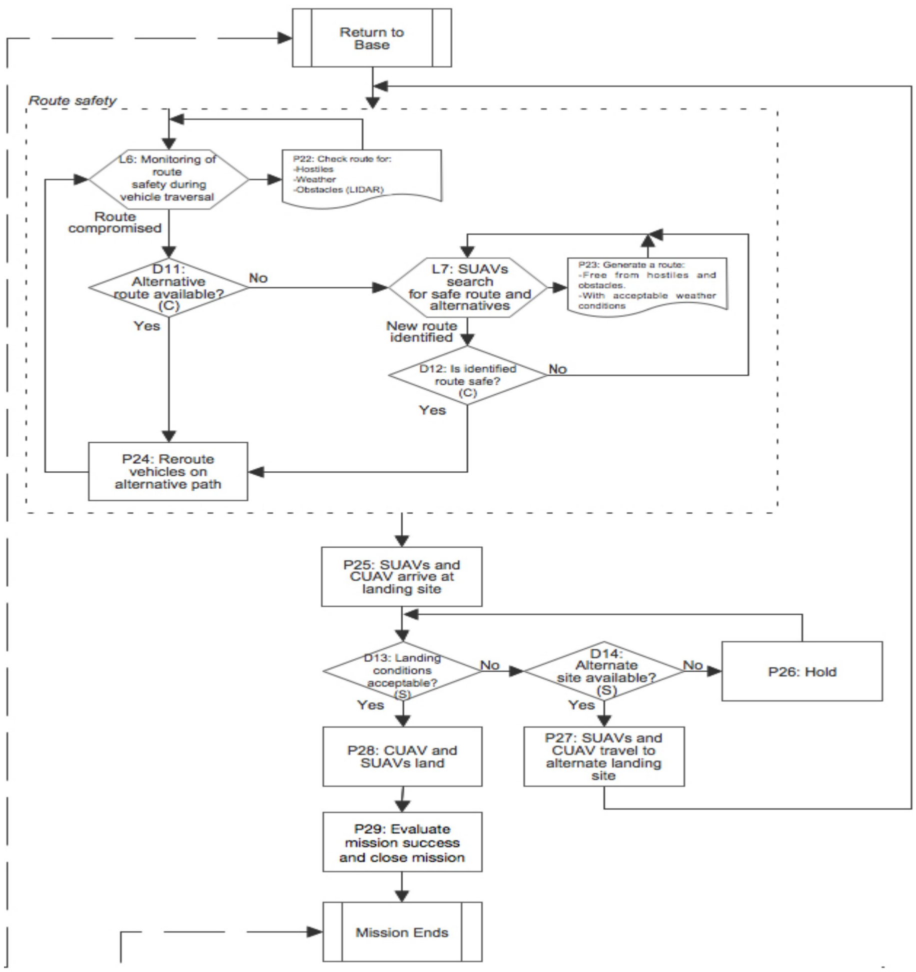


Figure 16: Event flow diagram for the *Return to Base* phase

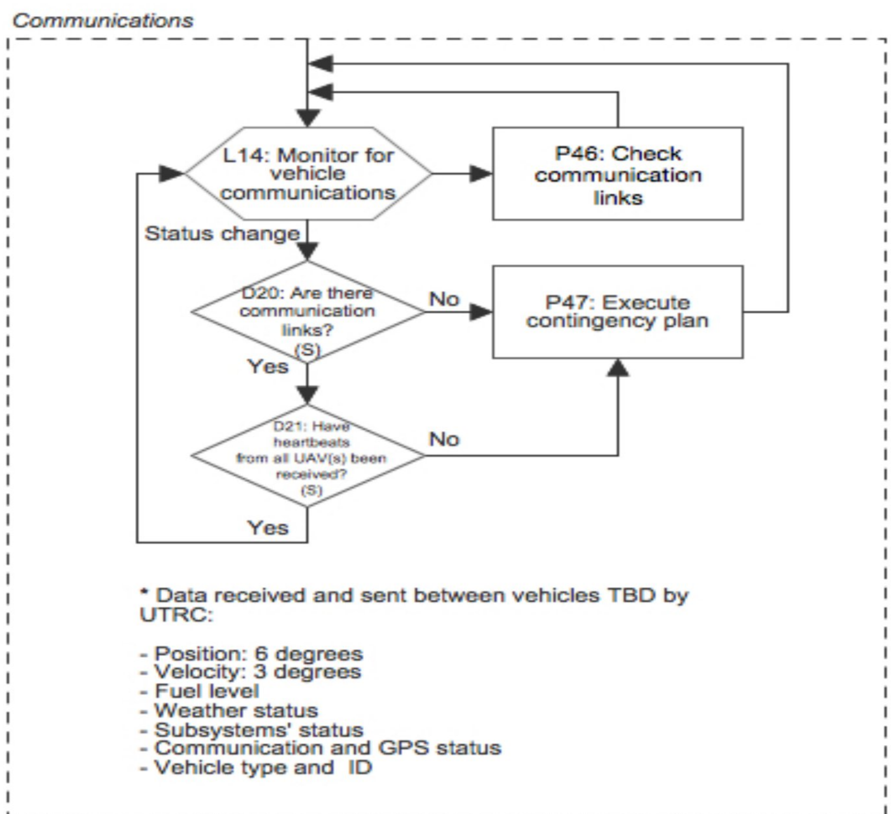


Figure 17: Event flow diagram for *Communications* continuous monitoring task

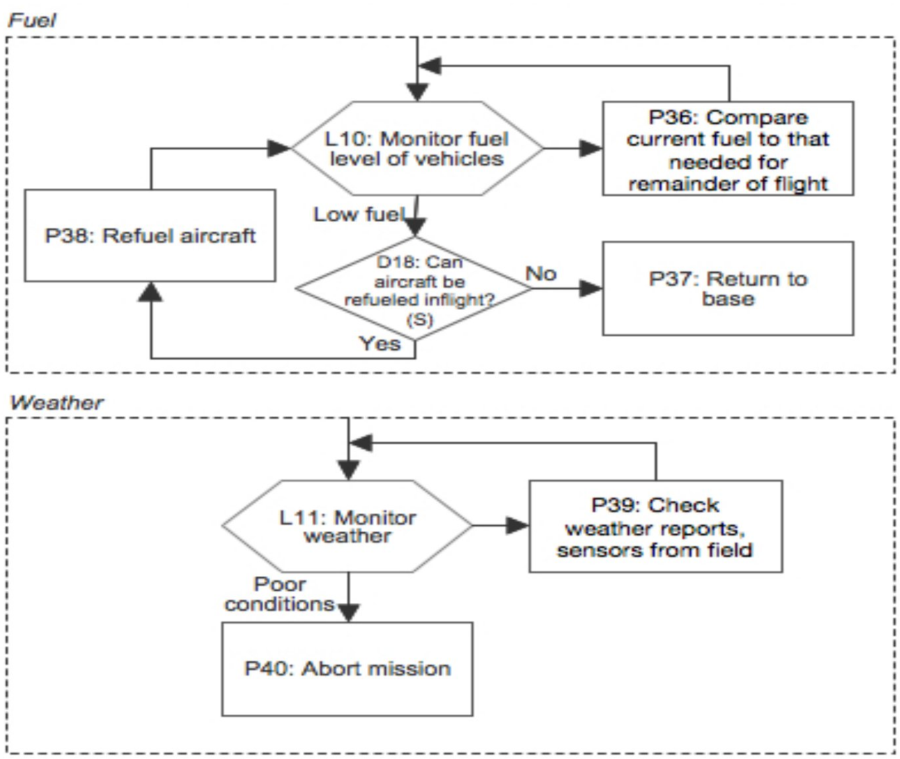


Figure 18: Event flow diagram for *Fuel* and *Weather* continuous monitoring tasks

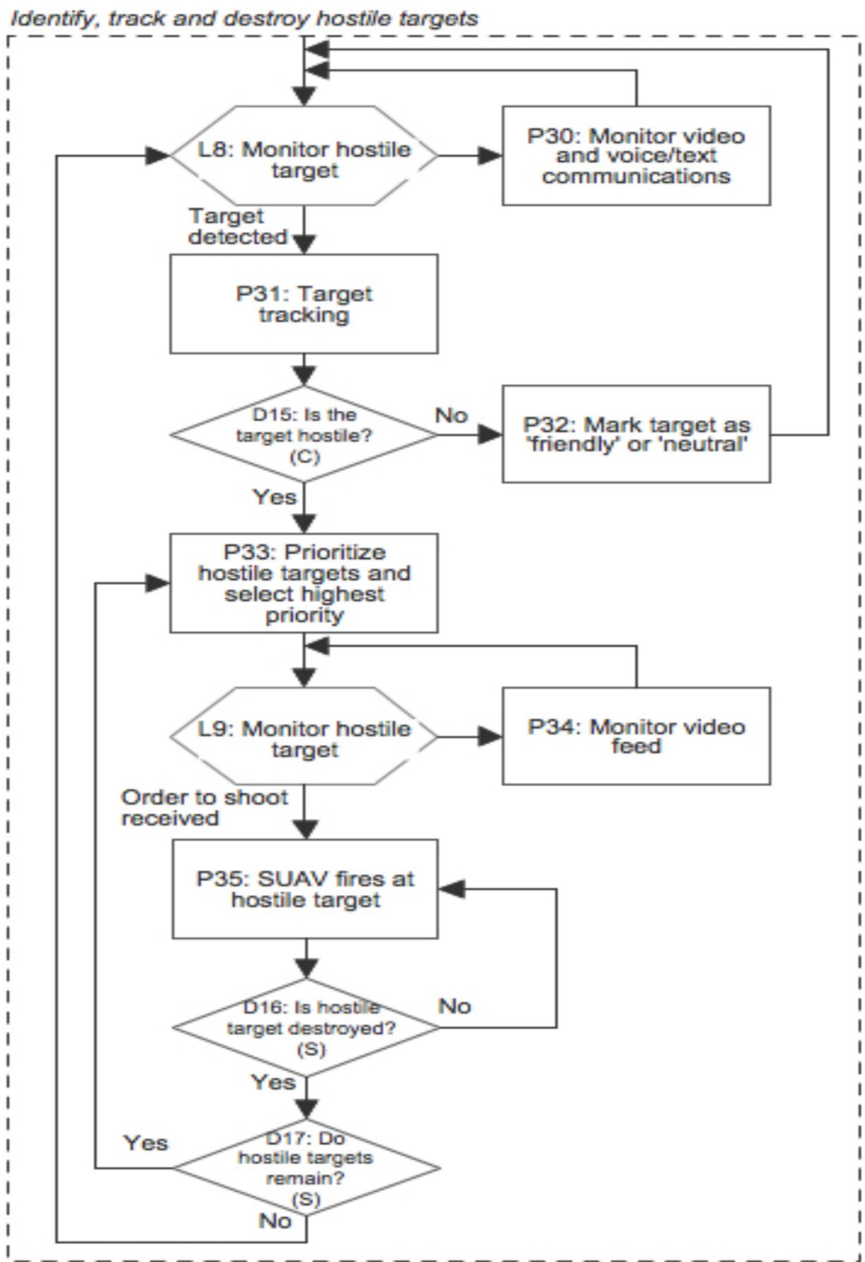


Figure 19: Event flow diagram for *Identify, Track, and Destroy Hostile Targets* continuous monitoring task

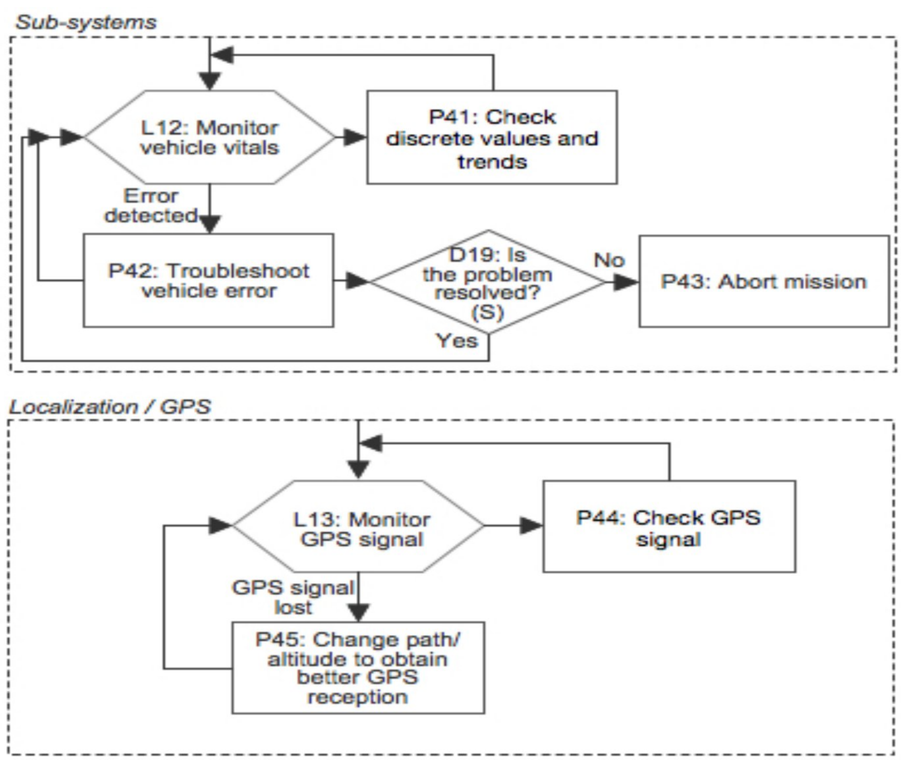


Figure 20: Event flow diagram for *Localization/GPS* and *Subsystems* continuous monitoring tasks

# Appendix B: Decision Ladder Diagrams

The full original decision ladder for "Is There a Suitable Initial/Alternative Route," is shown in Figure 21. Versions of this decision ladder annotated with display requirements and automation levels are given in Figures 22 and 23 respectively. The original decision ladder, a display requirements decision ladder, and an automation-level annotated decision ladder for "Is Identified Site Safe," are shown in Figures 24, 25 and 26.

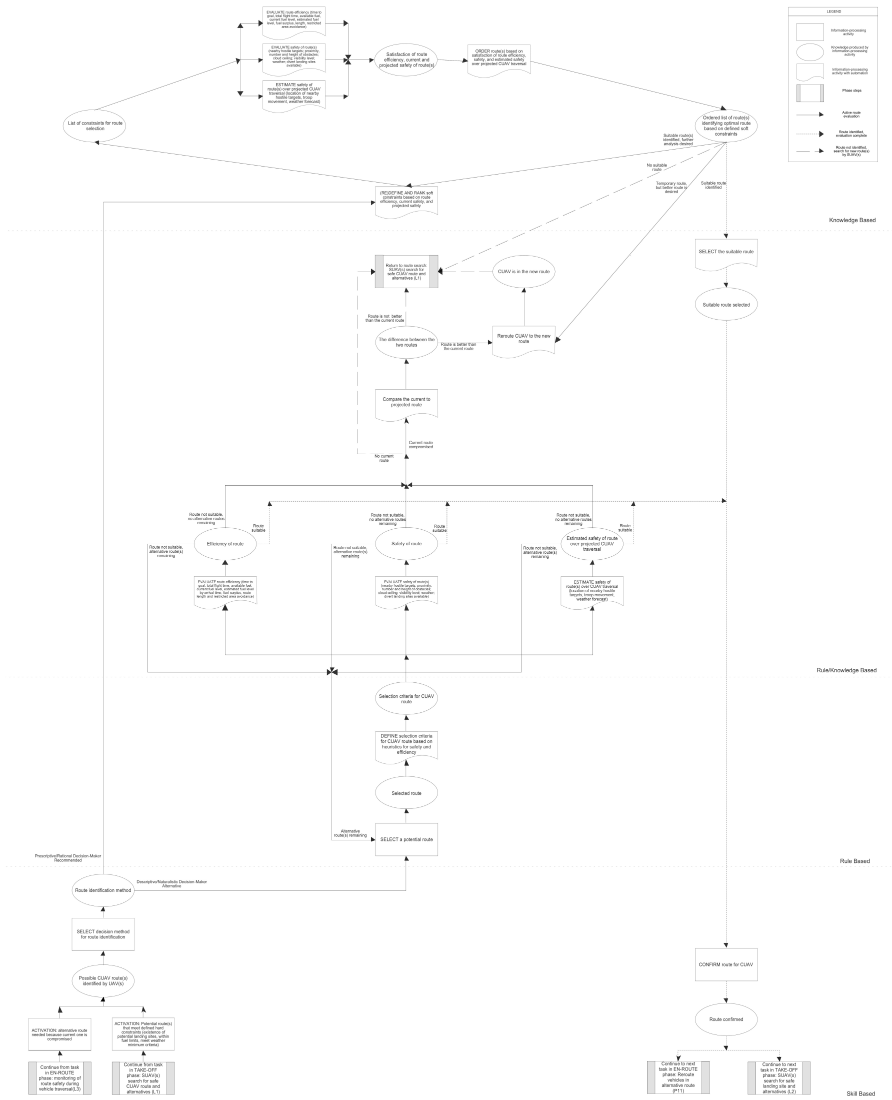


Figure 21: Original decision ladder for “Is There a Suitable Initial/Alternative Route?”

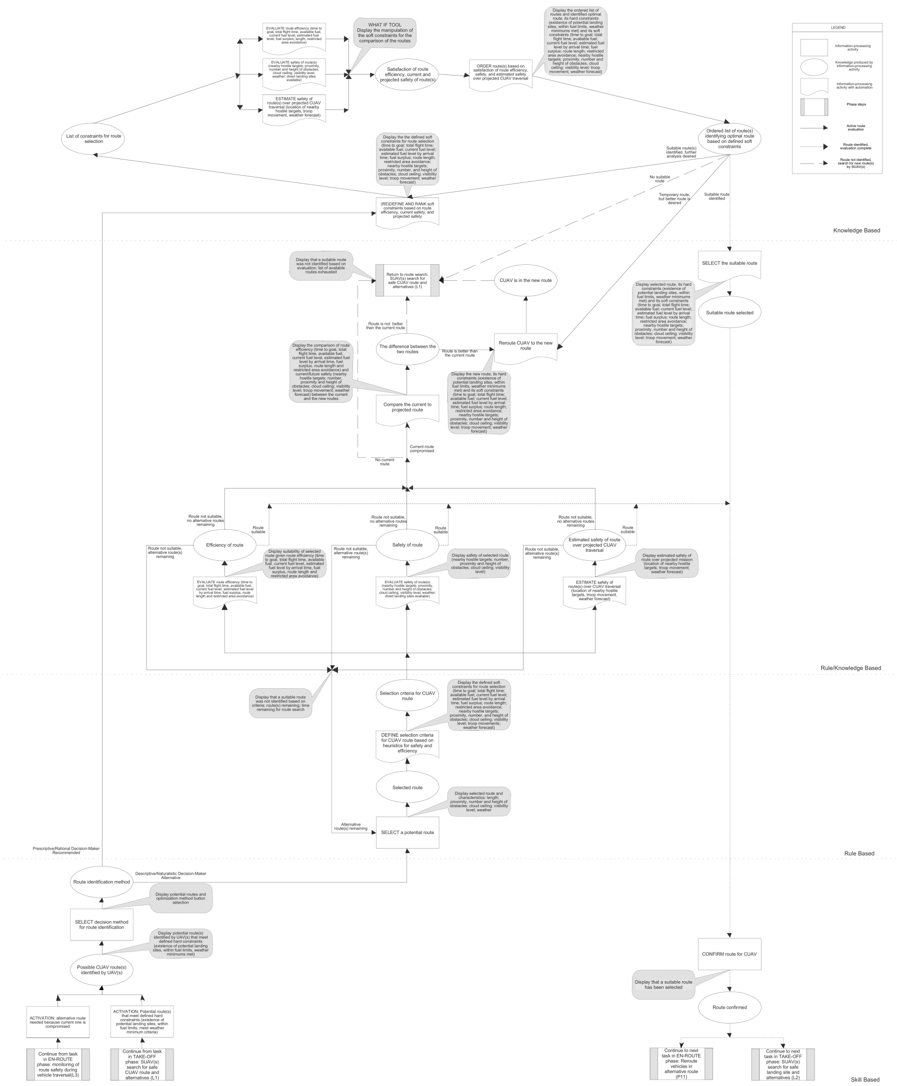

Figure 22: Decision ladder with display requirements for "Is There a Suitable Initial/Alternative Route?"

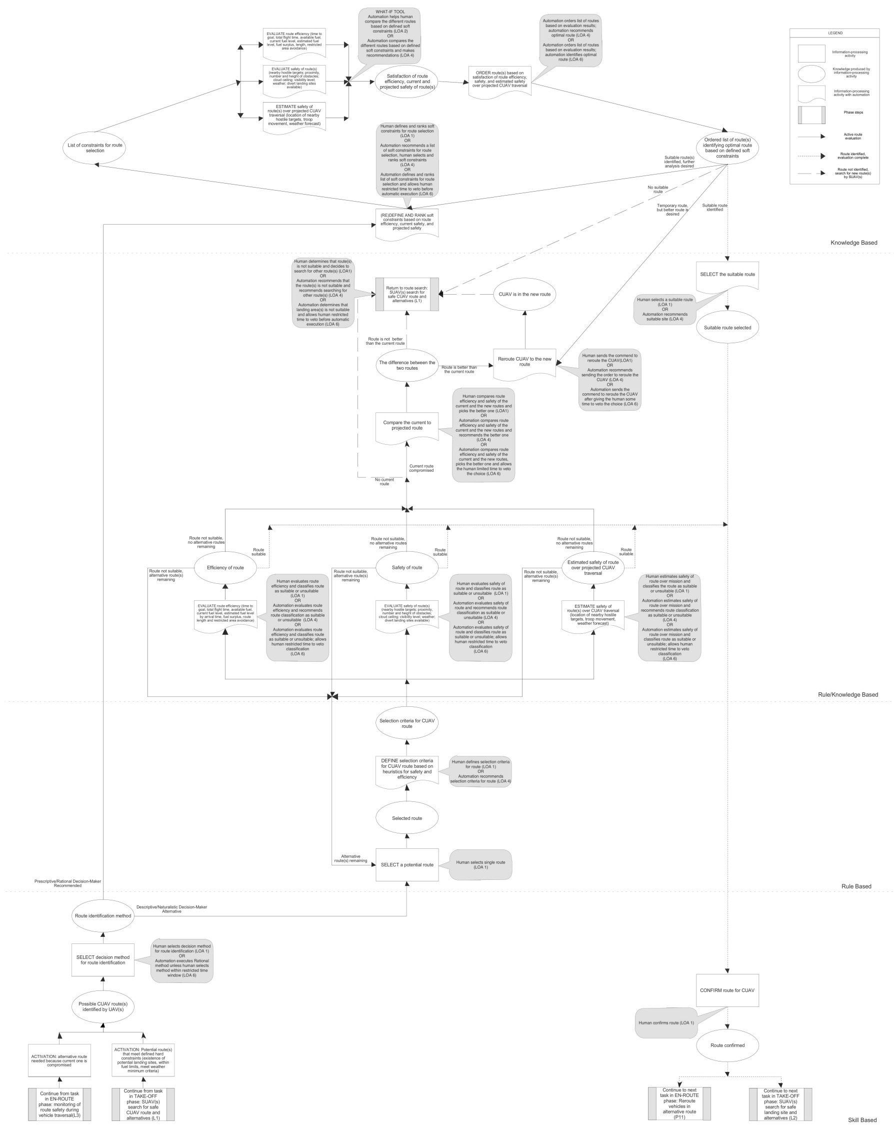


Figure 23: Decision ladder with automation level annotations for “Is There a Suitable Initial/Alternative Route?”

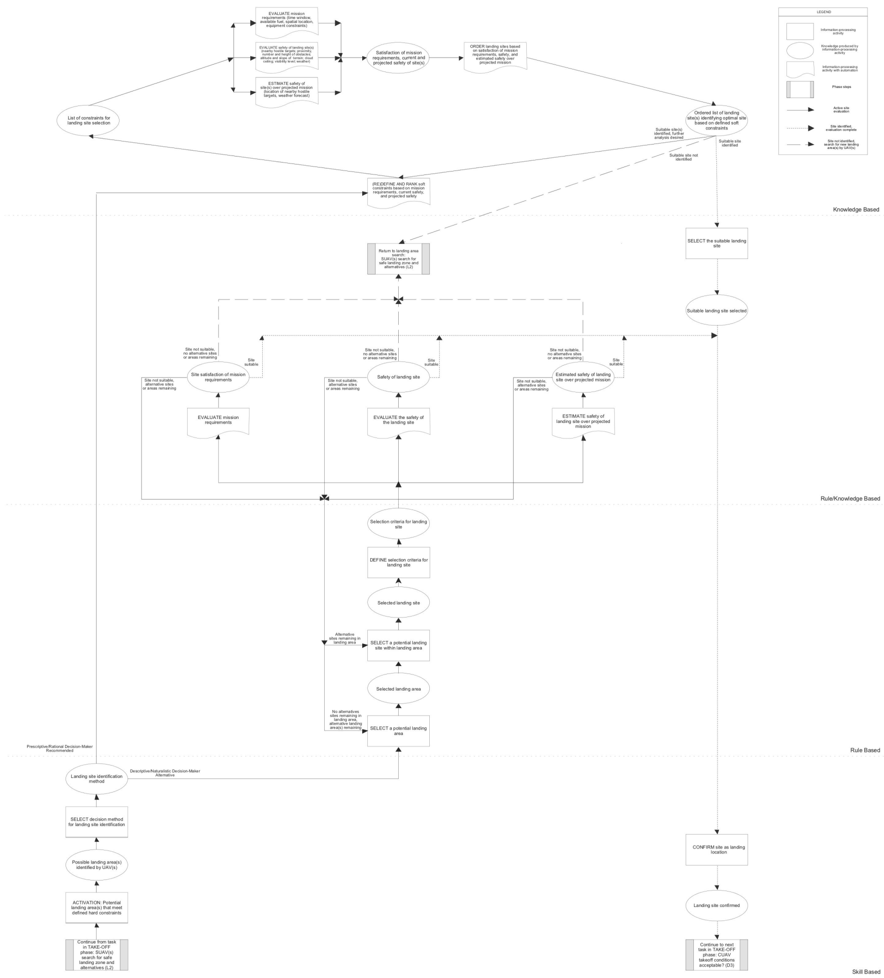

Figure 24: Original decision ladder for “Is Identified Site Safe?”

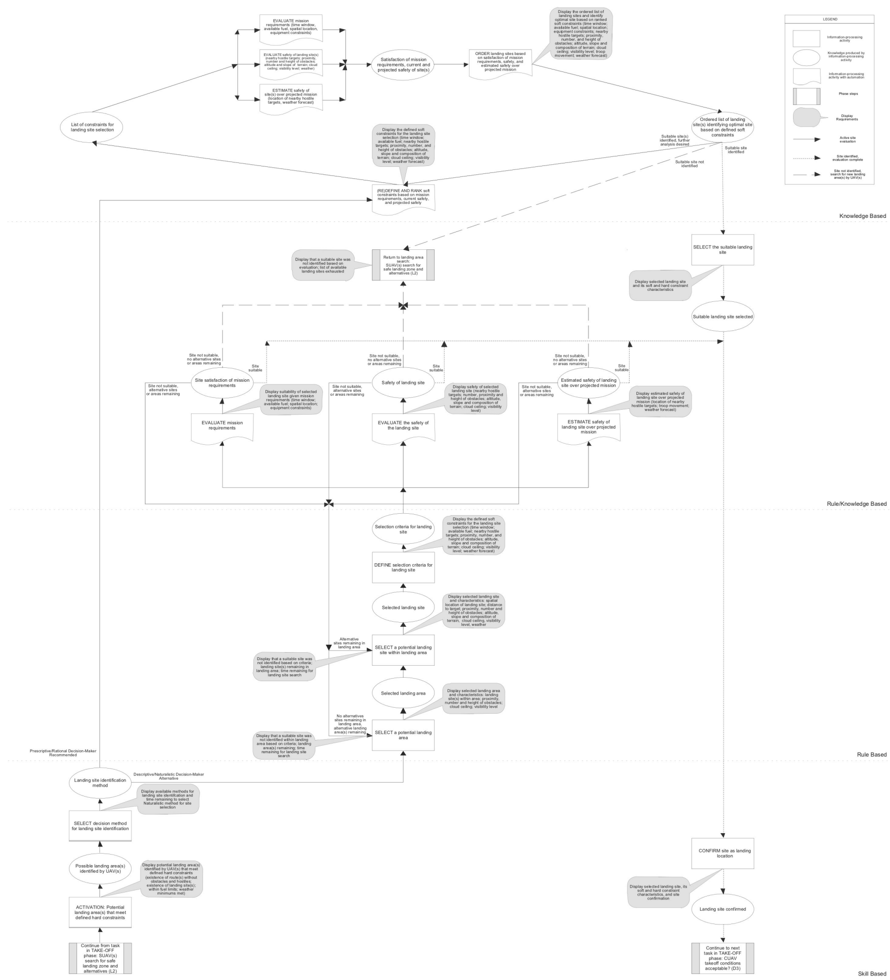


Figure 25: Decision ladder with display requirements for “Is Identified Site Safe?”

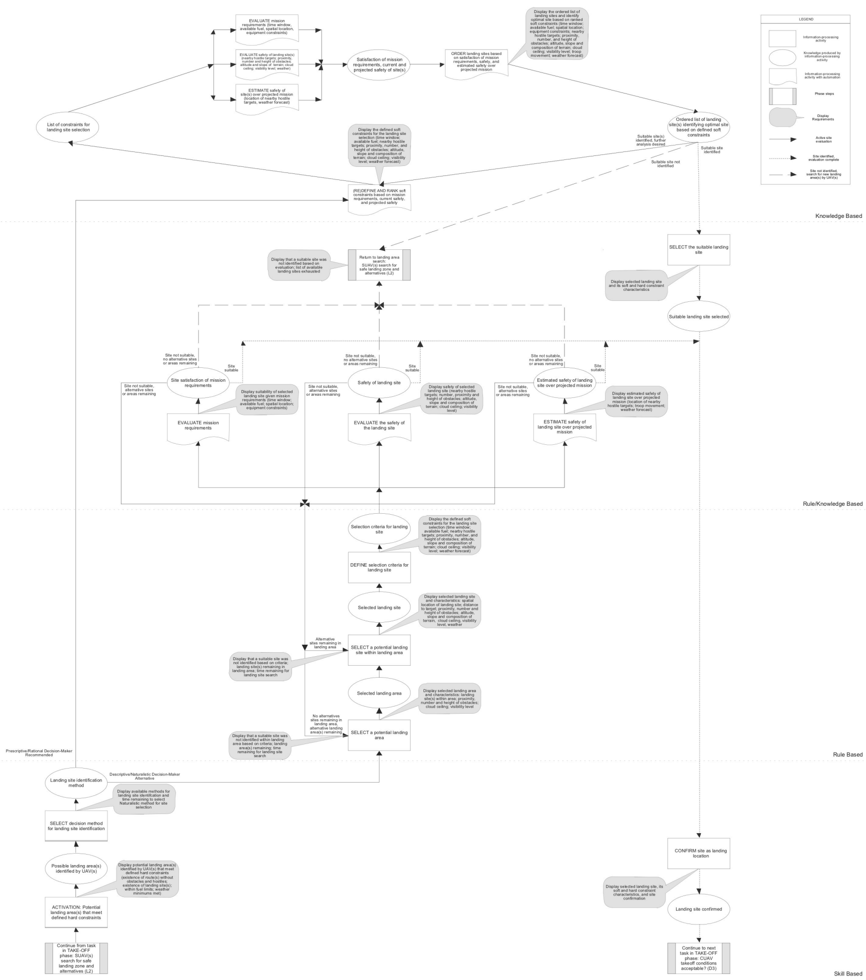


Figure 26: Decision ladder with automation level annotations for "Is Identified Site Safe?"

# Appendix C: Situation Awareness Requirements

The situation awareness requirements generated from the hCTA process for the phases *Takeoff*, *En Route*, *Insertion-Extraction*, *Return to Base*; and the monitoring tasks *Track, Identify, and Destroy Hostile Targets*, and *Vehicle Health Status* are given on the following 6 pages.

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
|---|---|---|---|---|
| Takeoff | 1 | Visual and auditory feedback that SUAV(s) have taken off (P1) | SUAV(s) successfully took off (P1) | |
| | | | SUAV(s)'s take off is delayed (P1) | Impact of a delay in SUAV(s)'s take off on schedule (P1) |
| | 2 | Visual feedback of the routes found by the SUAV(s) and their characteristics (number of hostiles, weather conditions, obstacles) (L1, P2) | Suitable routes found by SUAV(s) for CUAV (P2, DL1) | |
| | 3 | Visual feedback of landing sites found by the SUAV(s) and their characteristics (number of hostiles, weather conditions, terrain conditions, visibility level and obstacles) (L2, P3) | Suitable landing sites found by SUAV(s) for CUAV (P3, DL2) | |
| | 4 | Visual feedbacknof the weather conditions at the base (cloud ceiling level, visibility level, existence and strength of storms, temperature) (D3) | Weather condition acceptable for CUAV takeoff (D3) | |
| | | | Weather conditions not acceptable for CUAV takeoff (D3) | Impact of a delay in CUAV takeoff on schedule (D3) |
| | 5 | Visual and auditory feedback of the status of CUAV (engines, computers, electronics, brakes, flaps, oil and fuel level) for takeoff (D3) | CUAV's condition acceptable for takeoff (D3) | |
| | | | CUAV's condition not acceptable for takeoff (D3) | Impact of a delay in CUAV takeoff on schedule (P4) |
| | 6 | Visual and auditory feedback that CUAV has taken off (P5) | CUAV successfully took off (P5) | |
| | | | CUAV's take off is delayed (P5) | Impact of a delay in CUAV takeoff on schedule (P5) |

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
|---|---|---|---|---|
| **En Route** | 7 | Visual and auditory feedback of the number of escorts needed by CUAV (D4) | CUAV needs escorts (D4) | Changes on schedule according to the new SUAV(s)'s assignment (D4) |
| | | | CUAV does not need escorts (D4) | |
| | 8 | Visual feedback of position of CUAV while en route to landing site (P6) | Position and movement of CUAV (P6) | Estimated distance and time to reach the landing site (P6) |
| | 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) |
| | 12 | Visual feedback of the alternative safe routes found by the SUAV(s) and their characteristics (number of hostiles, weather conditions, obstacles) (L4, P10) | Available alternative suitable routes for CUAV (P10, DL1) | Changes on schedule based on the characteristics of the new suitable route (P11) |
| | | | No available suitable route for CUAV (P10, DL1) | Continue search for suitable routes (P10, DL1) |
| | 13 | Visual feedback of positions of SUAV(s) and CUAV on the current route (P11) | Position and movement of the vehicles (P11) | Distance and time to reach the landing site (P11) |
| | 14 | Visual and auditory feedback of the arrival of vehicles at the landing site (P12) | Vehicles arrived at the landing site in time (P12) | |
| | | | Vehicles have not reach the landing site in time (P12) | Impact of a delay in CUAV and SUAV(s) travel on schedule (P12) |

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
|---|---|---|---|---|
| Insertion/ Extraction | 16 | Visual feedback of the characteristics of the landing site (number of hostiles, weather conditions, terrain conditions, visibility level, obstacles) (D7) | Landing site acceptable for CUAV (D7) | |
| | | | Landing site not acceptable for CUAV (D7) | Impact of waiting for better landing conditions on schedule (P14) |
| | 17 | Visual and auditory feedback that CUAV has landed (P15) | CUAV successfully landed (P15) | |
| | | | CUAV did not land in the site in time (P15) | Impact of a delay in CUAV's landing on schedule (P15) |
| | 18 | Visual feedback of return routes found by SUAV(s) and their characteristics (number of hostiles, weather conditions, obstacles) (L5, P16) | Suitable return routes found by SUAV(s) for CUAV (P16) | |
| | 19 | Visual and auditory feedback of the status (time spent and remaining, the number and characteristics of remaining tasks) of on/off loading to/from CUAV (P17) | On/off loading to/from CUAV is done in the scheduled time (P17) | |
| | | | On/off loading to/from CUAV is not done in the scheduled time (P17) | Impact of a delay in the on/off loading to/from CUAV on schedule (P17) |
| | 20 | Visual feedback of the weather conditions for takeoff (cloud ceiling level, visibility level, existence and strength of storms) (D9) | Weather condition are acceptable for CUAV takeoff (D9) | |
| | | | Weather condition are not acceptable for CUAV takeoff (D9) | Impact of a delay in CUAV takeoff on schedule (P18) |
| | 21 | Visual feedback of the status of CUAV for takeoff (engines, computers, electronics, brakes, flaps, oil and fuel level) (D9) | CUAV's condition are acceptable for takeoff (D9) | |
| | | | CUAV's condition are not acceptable for takeoff (D9) | Impact of a delay in CUAV takeoff on schedule (P18) |
| | 22 | Visual and auditory feedback that CUAV has taken off (P19) | CUAV successfully took off (P19) | |
| | | | CUAV did not take off in time (P19) | Impact of a delay in CUAV take off on schedule (P19) |
| | 23 | Visual and auditory feedback of the number of escort(s) needed by CUAV during route traversal (D10) | CUAV needs escorts (D10) | |
| | | | CUAV does not need escorts (D10) | Changes on schedule according to the new SUAV(s)'s assignment (D10) |
| | 24 | Visual feedback of position of CUAV while en route to the base (P20) | Position and movement of CUAV (P20) | Estimated distance and time to reach the base (P20) |
| | 25 | Visual feedback of positions of SUAV(s) and CUAV while en route to the base (P21) | Position and movement of CUAV and SUAV(s) (P21) | Estimated distance and time to reach the base (P21) |

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
|---|---|---|---|---|
| **Return to Base** | 26 | Visual feedback of route safety (hostile movement, weather conditions and obstacle) during CUAV traversal (L6, P22) | Current route is safe (P22, DL1) | |
| | | | Current route compromised (P22, DL1) | Impact of the unsafe route on schedule (P24) |
| | 27 | Visual feedback of the alternative routes found by the SUAV(s) and their characteristics (number of hostiles, weather conditions, obstacles) (L7, P23) | Available alternative suitable routes for CUAV (P23, DL1) | Changes on schedule based on the characteristics of the new suitable route (P24) |
| | | | No available suitable route (P23, DL1) | Continue search for suitable routes (P23, DL1) |
| | 28 | Visual feedback of positions of SUAV(s) and CUAV on new route (P24) | Position and movement of the vehicles (P24) | Estimated distance and time to reach the landing site (P24) |
| | 29 | Visual and auditory feedback of the arrival of vehicles at the landing site (P25) | Vehicles arrived at the landing site in time (P25) | |
| | | | Vehicles did not reach the landing site in time (P25) | Impact of a delay in vehicles' travel on schedule (P25) |
| | 30 | Visual feedback of the weather conditions for landing (cloud ceiling level, visibility level, existence and strength of storms) (D13) | Weather condition is acceptable for CUAV landing (D13) | |
| | | | Weather condition is not acceptable for CUAV landing (D13) | Impact of a delay in CUAV landing on schedule (P26) |
| | 31 | Visual feedback of the alternative landing sites found by the SUAV(s) and their characteristics (number of hostiles, weather conditions, terrain conditions, visibility level, obstacles) (D14) | Available alternative landing sites for CUAV and SUAV(s) (D14, DL2) | Changes on schedule based on the characteristics of the new suitable route (P27) |
| | | | No available alternative landing sites for CUAV and SUAV(s) (D14, DL2) | Changes on schedule based on the wait for the conditions to better (P26) |
| | 32 | Visual feedback of positions of CUAV and SUAV(s) while en route to the new landing site (P27) | Position and movement of vehicle (P27) | Estimated distance and time to reach the landing site (P27) |
| | 33 | Visual and auditory feedback that CUAV and SUAV(s) have landed (P28) | CUAV successfully landed (P28) | |
| | | | CUAV did not land in time (P28) | Impact of a delay of CUAV landing on schedule (P28) |
| | 34 | Visual feedback of the analysis of mission (success of insertion/extraction within required time, number and severity of damaged vehicles, number and severity of human injuries) (P29) | Mission completed with success (P29) | |
| | | | Mission was not completed with success (P29) | |

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
|---|---|---|---|---|
| Identify, track and destroy hostile targets | 35 | Visual and auditory feedback of the search area and the potential targets (L8, P30) | Potential targets in the surrounding area (L8) | Impact of tracking the potential targets on schedule (P31) |
| | | | No potential targets in the surrounding area (L8) | |
| | 36 | Video footage of the target being tracked and visual feedback of its characteristics (position, speed, nationality, weapon capability) (P31) | Position and movement of the target being tracked (P31) | Future position of the target being tracked (P31) |
| | 37 | Visual or auditory feedback of the identification of the target (D15) | Targets identified as hostile (P32) | Impact of changing the list of hostile targets (P33) |
| | | | Target identified as neutral (P32) | |
| | | | Target identified as friendly (P32) | |
| | 38 | Visual feedback of the ordered list of hostile targets and requirements for prioritizing (hostile target position, speed, weapon capability, nationality) (P33) | List of hostile targets ordered according to requirements (P33) | |
| | | | List of hostile targets in not order according to requirements (P33) | Impact of reordering list of hostile targets (P33) |
| | 39 | Visual feedback of hostile target with the highest priority and its characteristics (position, speed, weapon capability, nationality) (L9, P34) | Hostile target ready for engagement (L9) | Impact of firing the hostile target (P35) |
| | | | Hostile target is not ready for engagement (L9) | Impact of continuing hostile target monitoring (L9) |
| | 40 | Video feed of the hostile target after the attack (D16) | Hostile target was destroyed (D16) | |
| | | | Hostile target was not destroyed (D16) | Impact of continuing the attack (P35) |
| | 41 | Visual feedback of remaining hostile targets and requirements for prioritizing (D17) | List of hostile targets ordered according to requirements (D17) | |
| | | | List of hostile targets in not order according to requirements (D17) | Impact of reordering list of hostile targets (P33) |

| Phase | SAR # | Level I (Perception) | Level II (Comprehension) | Level III (Projection) |
| --- | --- | --- | --- | --- |
| Vehicle Health and Status | 42 | Visual feedback of current fuel level (L10) | Fuel level is sufficient for the completing the mission (P36) | |
| | | | Fuel level is not sufficient for the completing the mission | Impact of changing schedule according to refueling needs (D18) |
| | 43 | Visualy feedback of aircraft capability for inflight refueling (D18) | Aircraft is capable to do inflight refueling (P38) | Impact of changing schedule according to refueling possibilities (P37, P38) |
| | | | Aircraft is not capable to do inflight refueling (P37) | Impact of changing schedule according to refueling possibilities (P37, P38) |
| | 44 | Visual feedback of weather status (cloud ceiling level, visibility level, existence and strength of storms, temperature) (L11, P39) | Vehicle is capable to fly in the weather condition (L11) | |
| | | | Vehicle is not capable to fly in the weather condition (L11) | Impact of mission abortion (P40) |
| | 45 | Visual of status of vehicles' vitals (engines, computers, electronics, brakes, flaps, oil level, fuel mixture) (L12, P41) | Vehicle is in good flight condition (L12) | |
| | | | Vehicle is not in good flight condition (L12) | Impact of error troubleshooting P42) |
| | 46 | Visual or auditory feedback of alerts and warnings about vehicle vitals (engines, computers, electronics, brakes, flaps, oil level, fuel mixture) (P42) | Recognition of the existence errors and their severity (P42) | Impact of error troubleshooting (P42) |
| | 47 | Visual feedback of the status of the errors about vehicle vitals (engines, computers, electronics, brakes, flaps, oil level, fuel mixture) (D19) | Error fixed (D19) | |
| | | | Error not fixed (D19) | Impact of mission abortion (P43) |
| | 48 | Visual feedback of GPS signal strength (L13, P44) | GPS signal exist (L13) | |
| | | | GPS signal does not exist or is too weak (L13) | Impact of changing path to find better GPS (P45) |
| | 49 | Visual and auditory feedback of the communication between the vehicles and the base (L14, P46, D21) | Messages are received and sent (L14, D21) | |
| | | | No message are received or sent (L14, D21) | Impact of executing contingency plan (P47) |
| | | | Heartbeats are received and sent (D20) | |
| | 50 | Visual indication of the strength of the communication links between vehicles and base (D20) | No heartbeats are received and sent (D20) | Impact of executing contingency plan (P47) |

# Appendix D: Storyboards and Cognitive Walkthrough

Storyboards for the interface design which were also used to perform a cognitive walkthrough exercise with test pilots at Sikorsky are given in the following 62 pages.

# Multi Autonomous Vehicle Insertion and Extraction System

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**Humans and Automation Lab, MIT**
**Sponsored by UTRC**

December 20, 2011

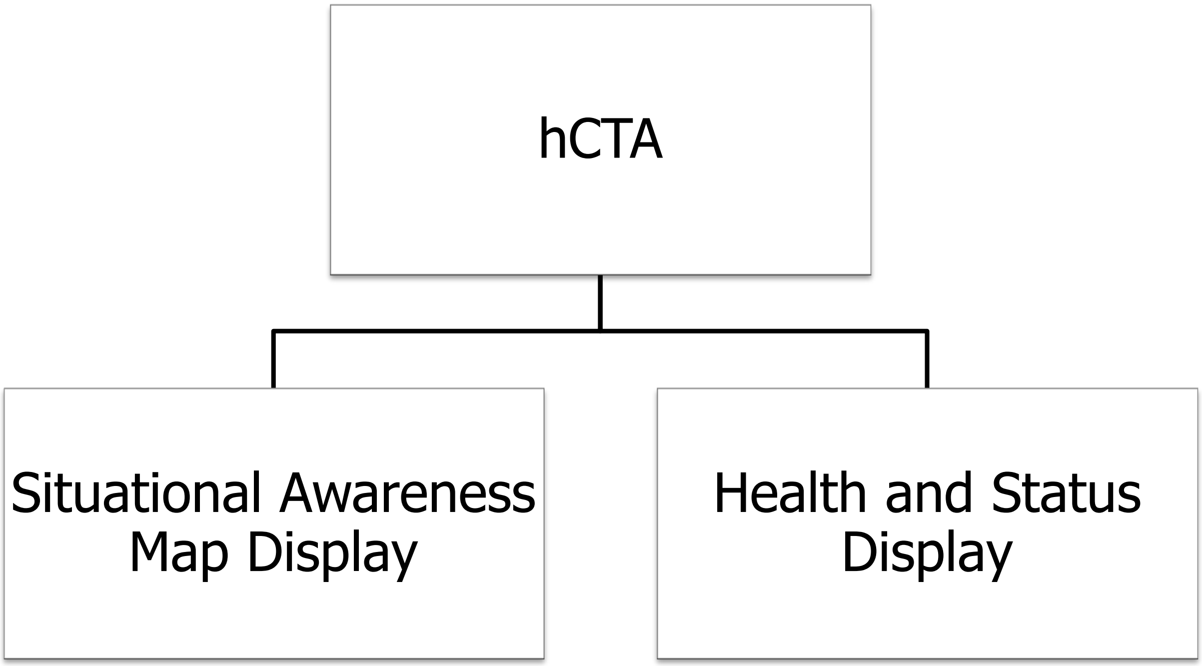


United Technologies Research Center

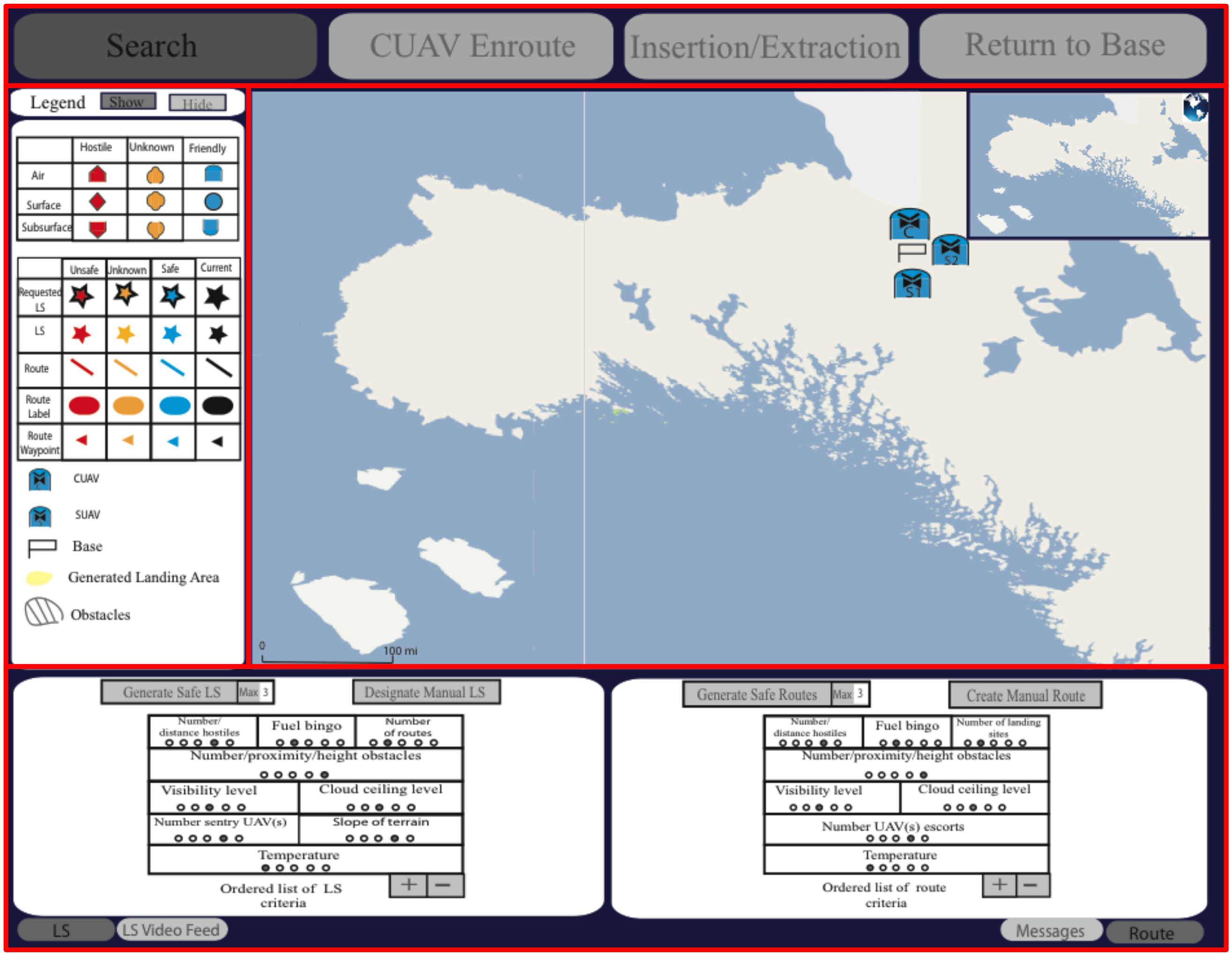
# Mission

Develop a user interface to perform insertion and extraction of personnel and supplies in hostile environments.

1 Cargo UAV (CUAV) & 2 Support UAVs (SUAVs)

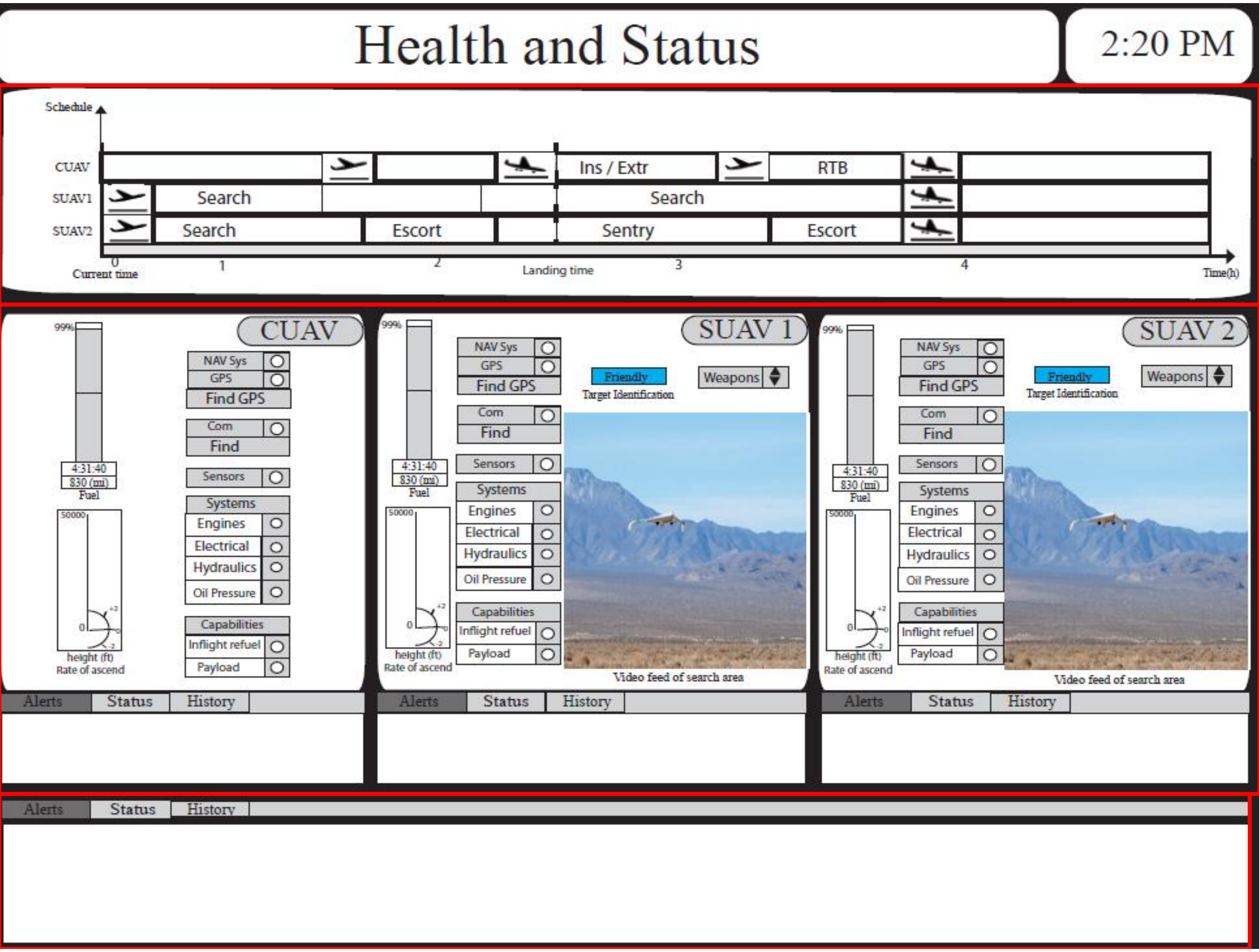


# Situational Awareness Map Display



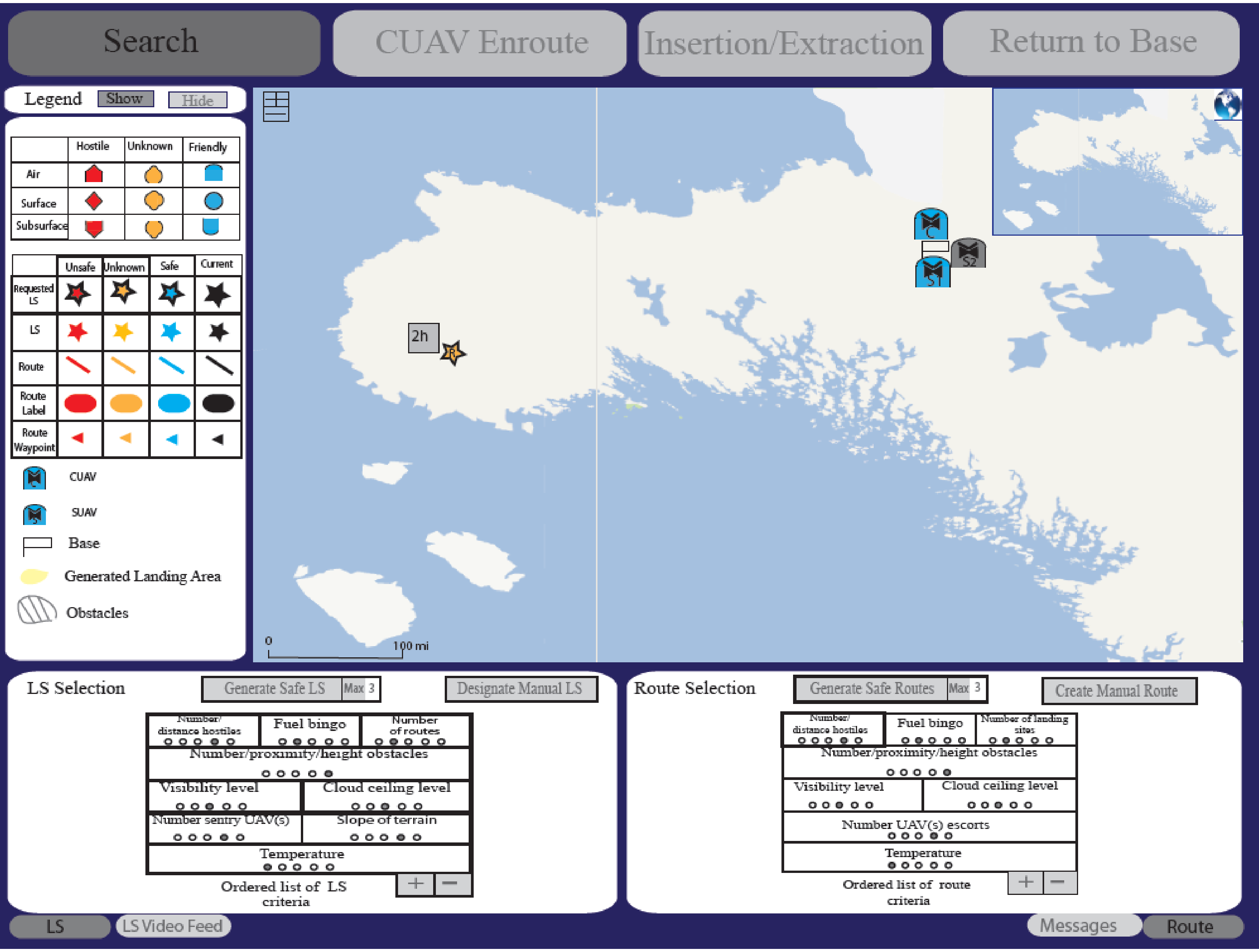



United Technologies Research Center

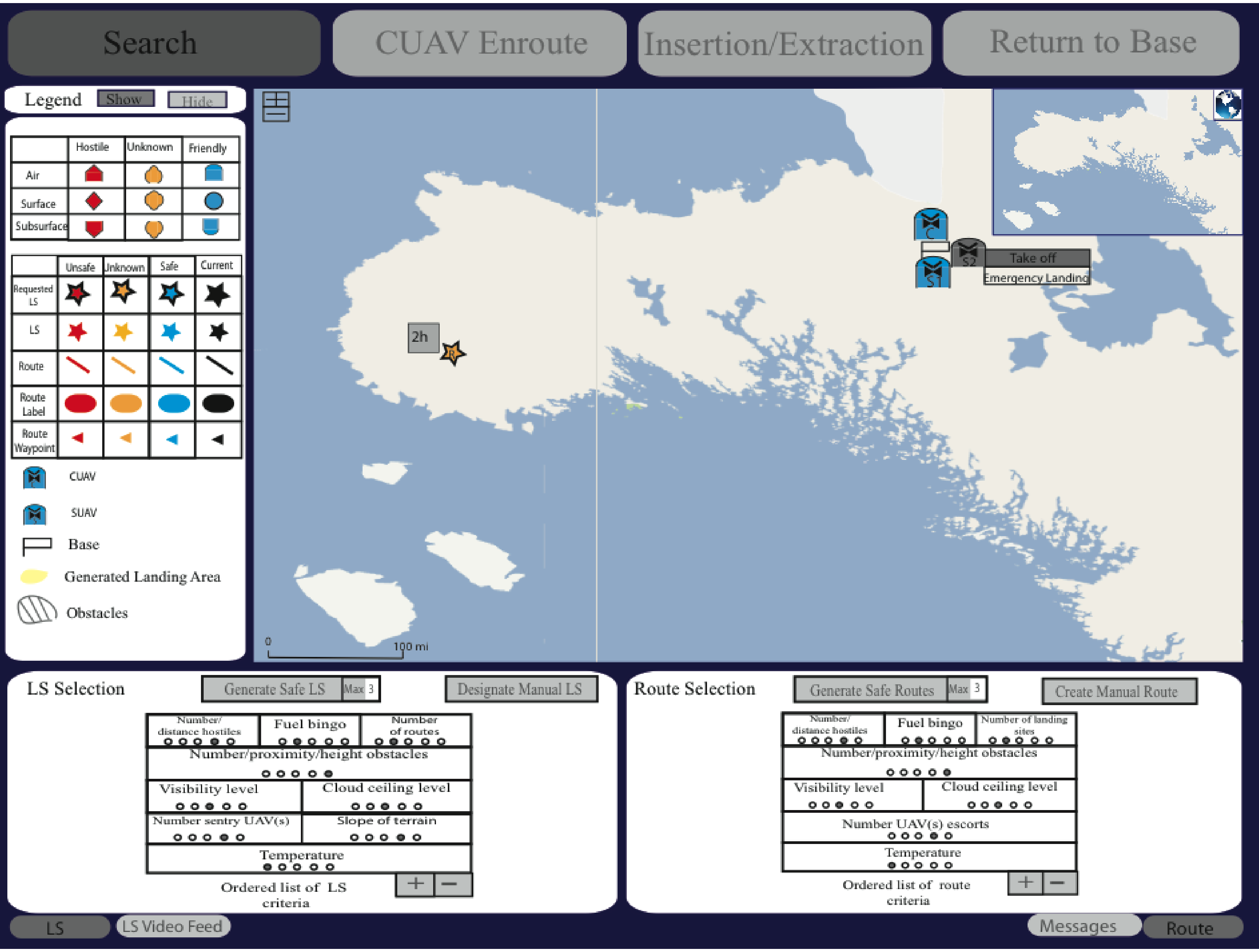


Health and Status
2:20 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
Current time
1
2
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Alerts
Status
History
SUAV 1
Friendly
Target Identification
Weapons
Video feed of search area
SUAV 2

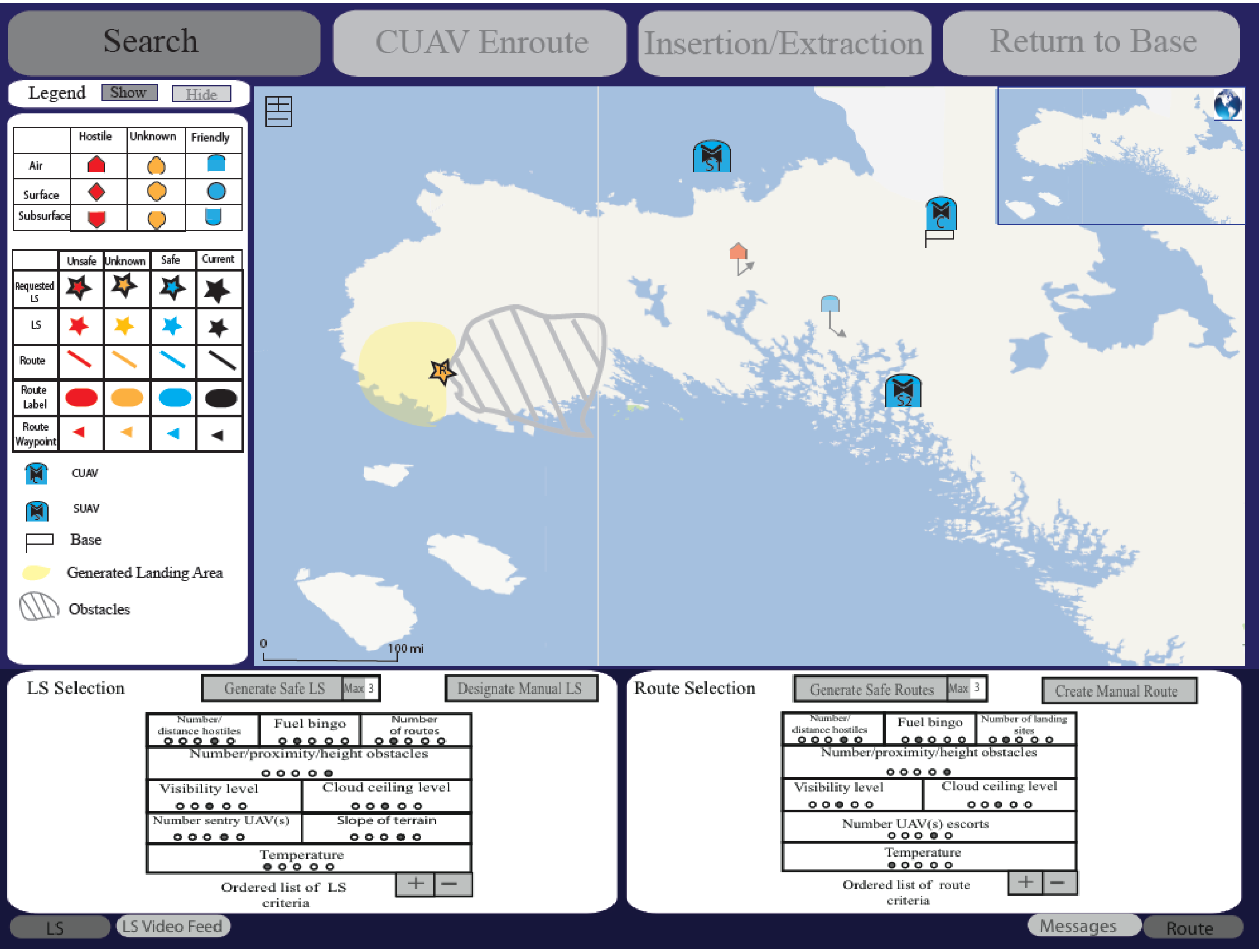
# Situational Awareness Map Cognitive Walkthrough

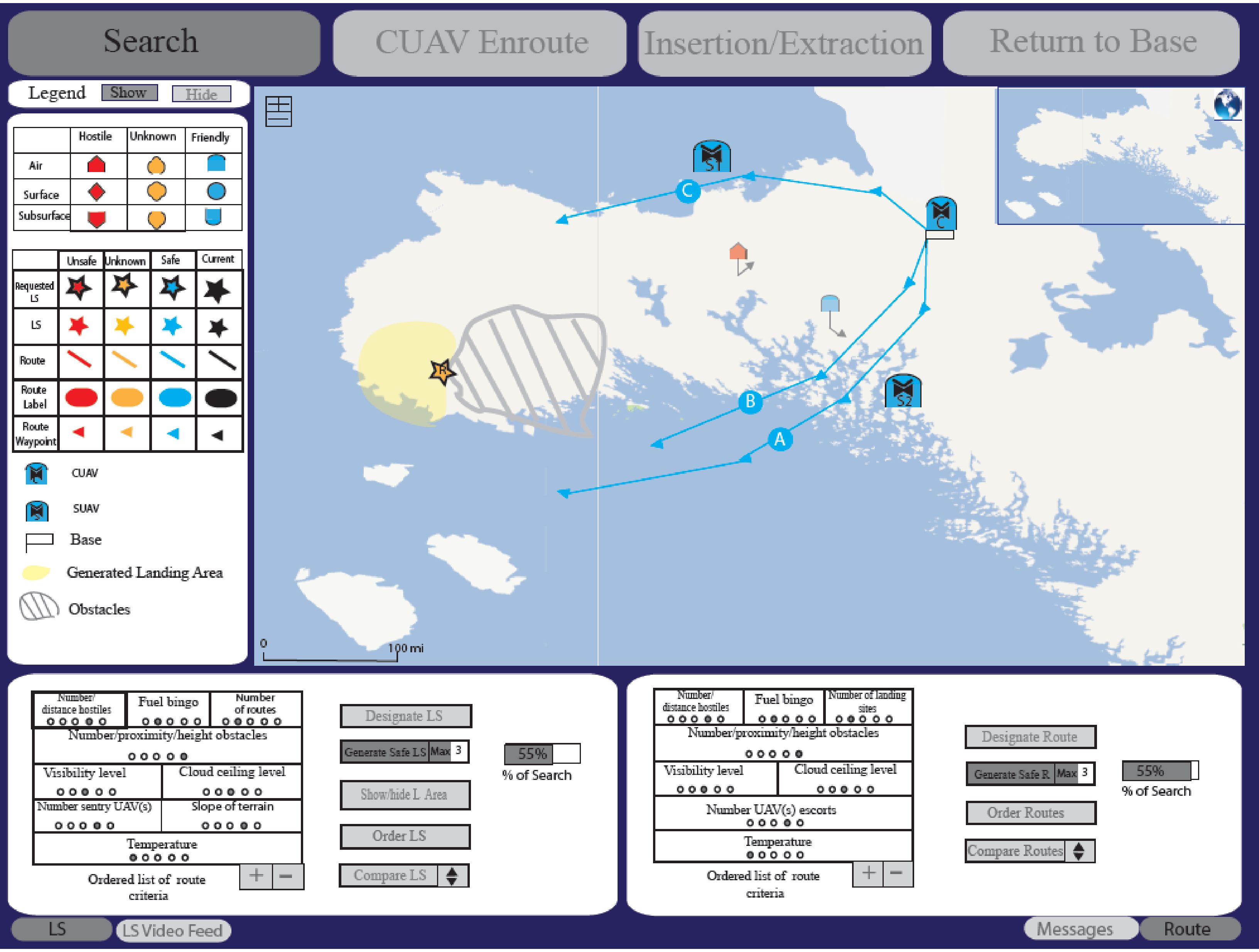


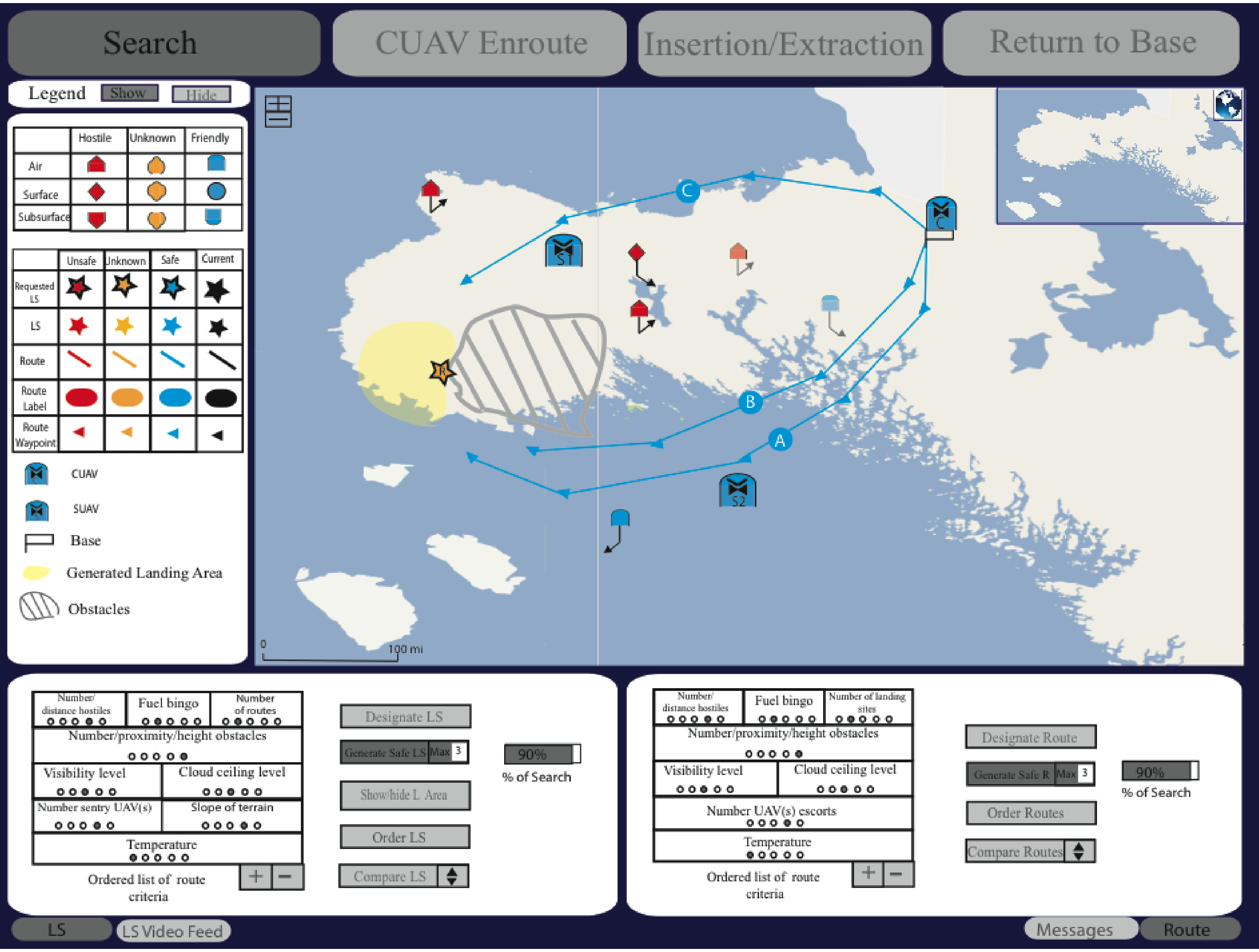
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
2h
0
100 mi
LS Selection
Generate Safe LS
Max 3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

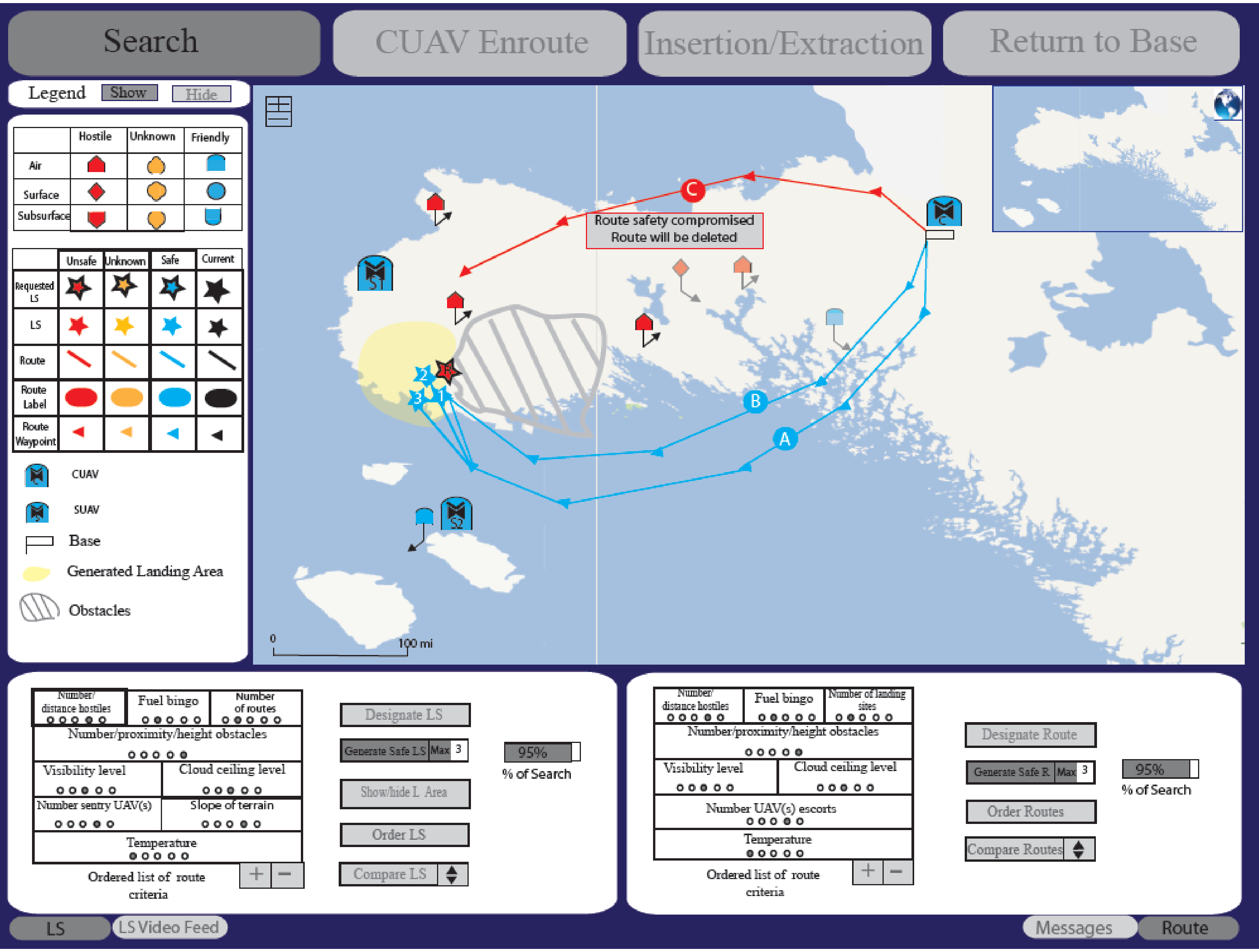

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
2h
Take off
Emergency Landing
0
100 mi
LS Selection
Generate Safe LS
Max 3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

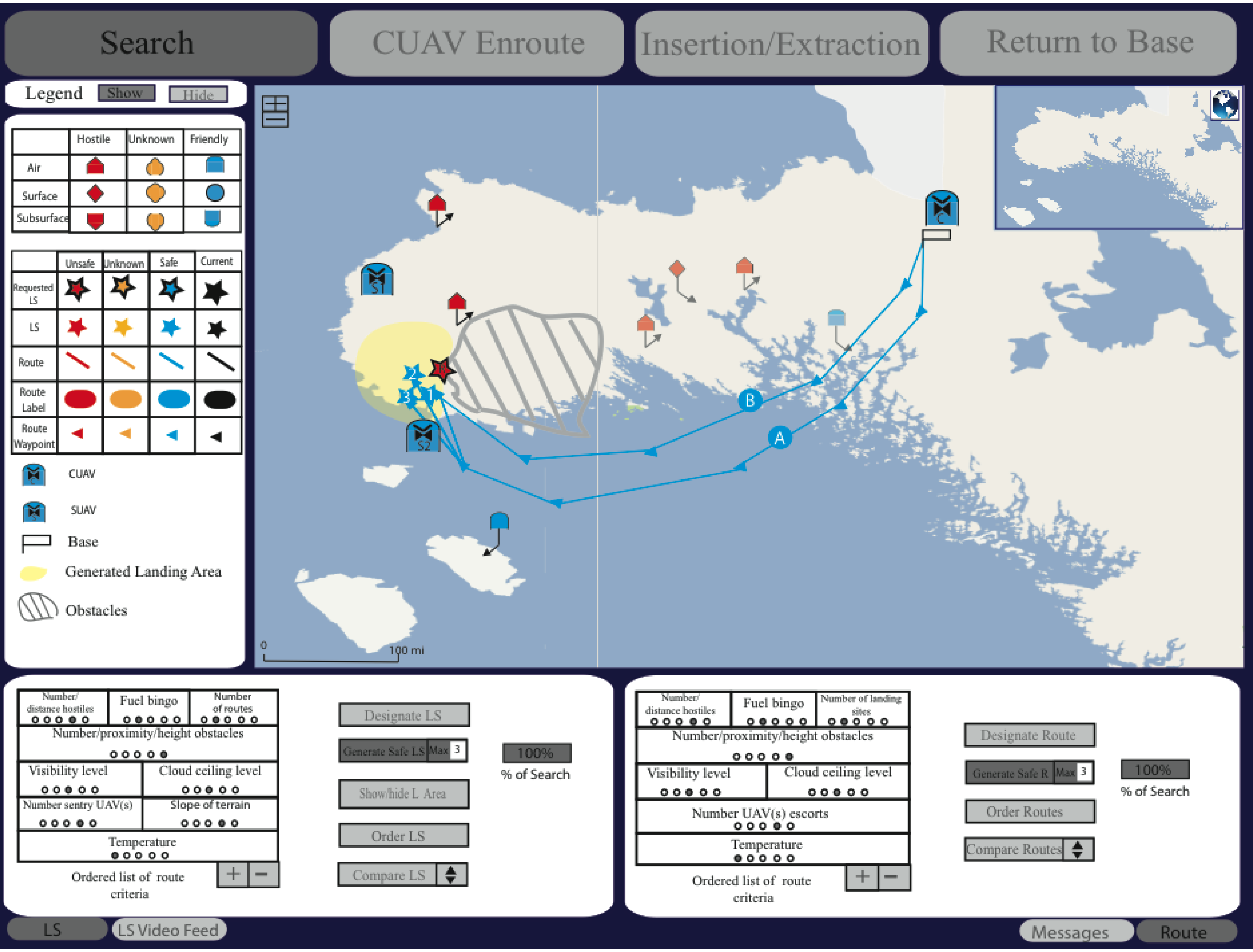
# Goal: Generate a Landing Site and Route

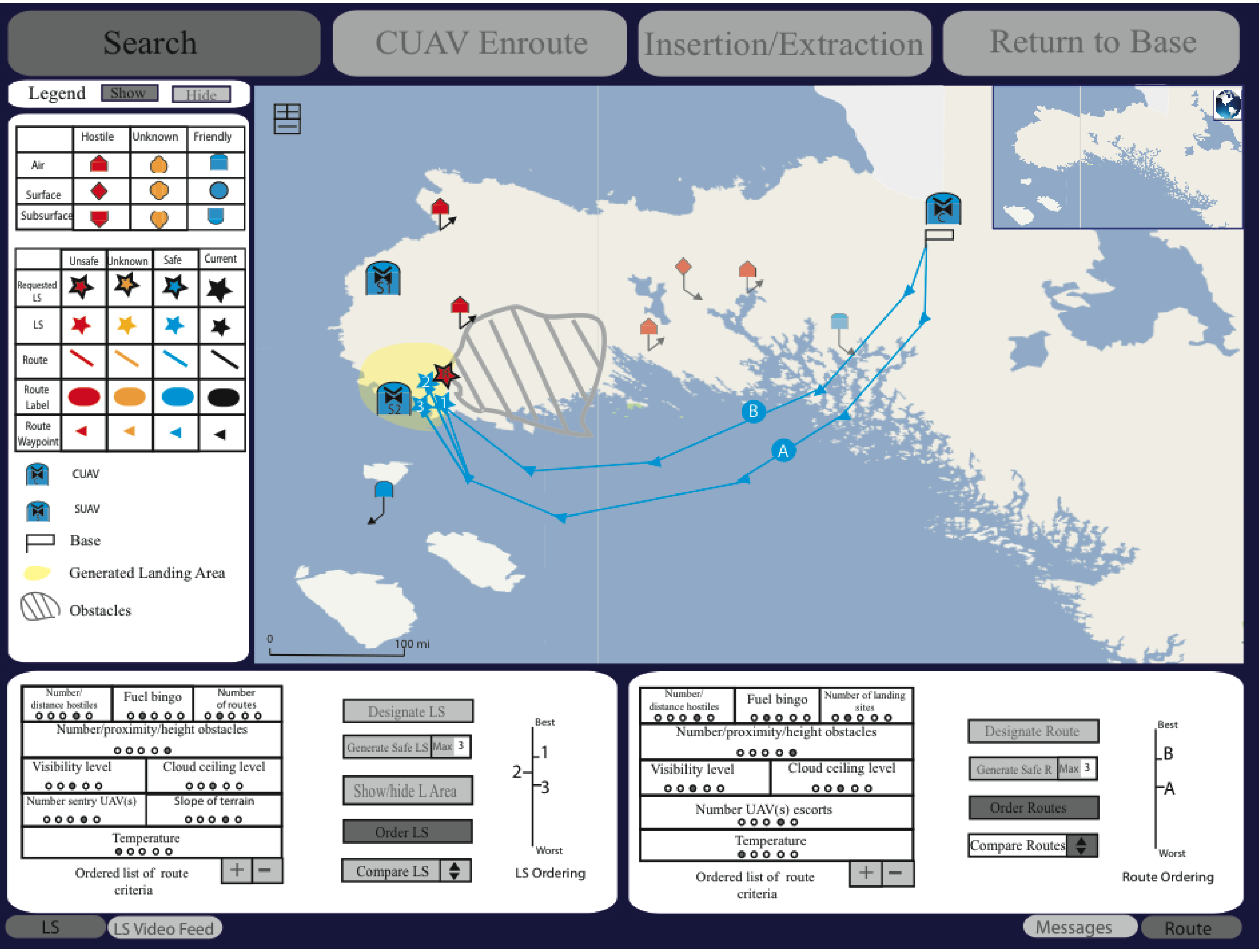

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
LS Selection
Generate Safe LS
Max 3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
S1
C
S2
A
B
C
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Designate LS
Generate Safe LS
Max
3
Show/hide L Area
Order LS
Compare LS
55%
% of Search
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max
3
Order Routes
Compare Routes
55%
% of Search
LS
LS Video Feed
Messages
Route

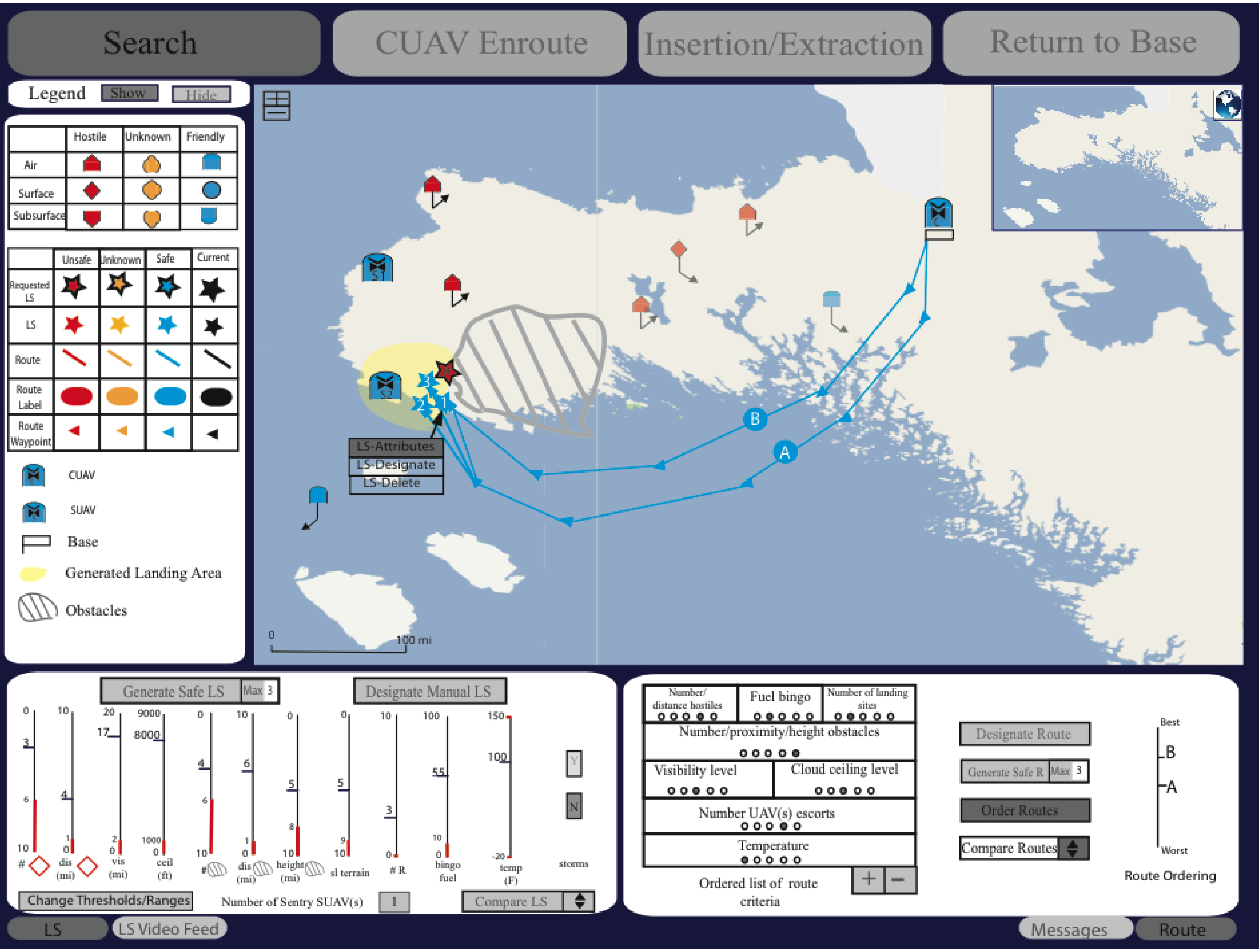

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
A
B
0
100 mi
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Designate LS
Generate Safe LS
Max
3
90%
% of Search
Show/hide L Area
Order LS
Compare LS
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max
3
90%
% of Search
Order Routes
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Route safety compromised
Route will be deleted
0
100 mi
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Designate LS
Generate Safe LS
Max
3
Show/hide L Area
Order LS
Compare LS
95%
% of Search
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max
3
Order Routes
Compare Routes
95%
% of Search
LS
LS Video Feed
Messages
Route

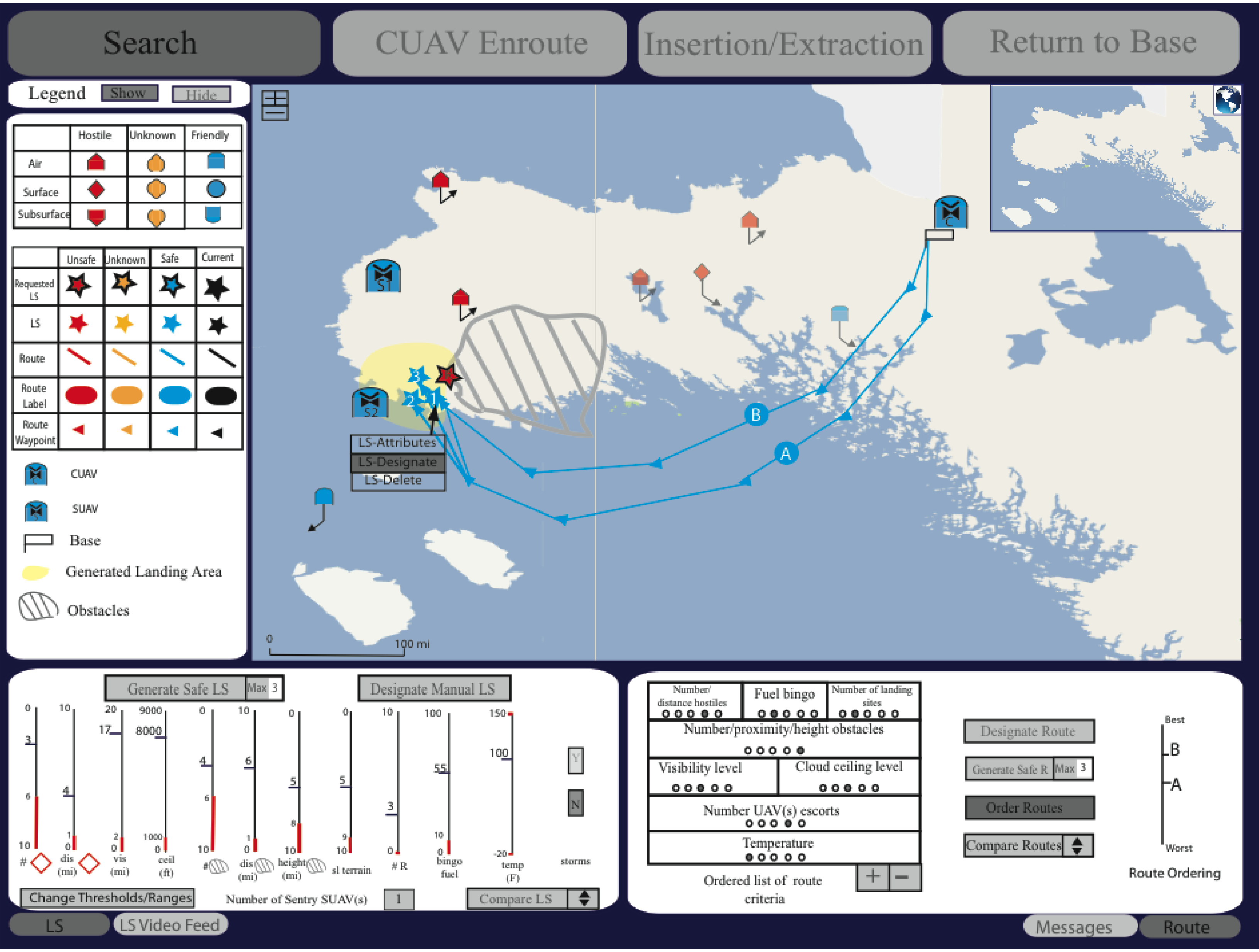

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
A
B
1
2
3
0
100 mi
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Designate LS
Generate Safe LS
Max
3
Show/hide L Area
Order LS
Compare LS
100%
% of Search
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max
3
Order Routes
Compare Routes
100%
% of Search
LS
LS Video Feed
Messages
Route



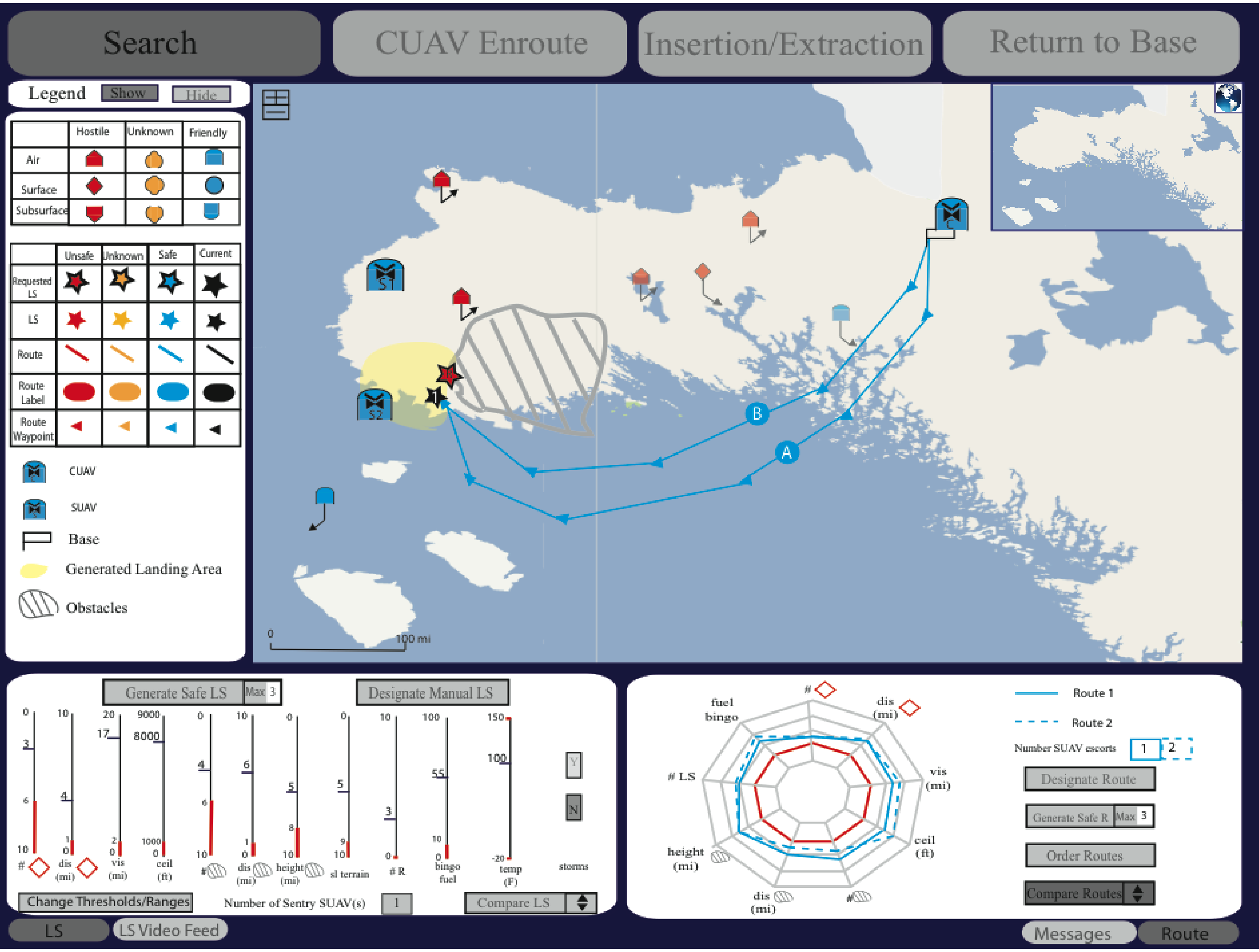
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
1
2
3
A
B
0
100 mi
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Designate LS
Generate Safe LS
Max
3
Show/hide L Area
Order LS
Compare LS
Best
Worst
LS Ordering
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max
3
Order Routes
Compare Routes
Best
Worst
Route Ordering
LS
LS Video Feed
Messages
Route

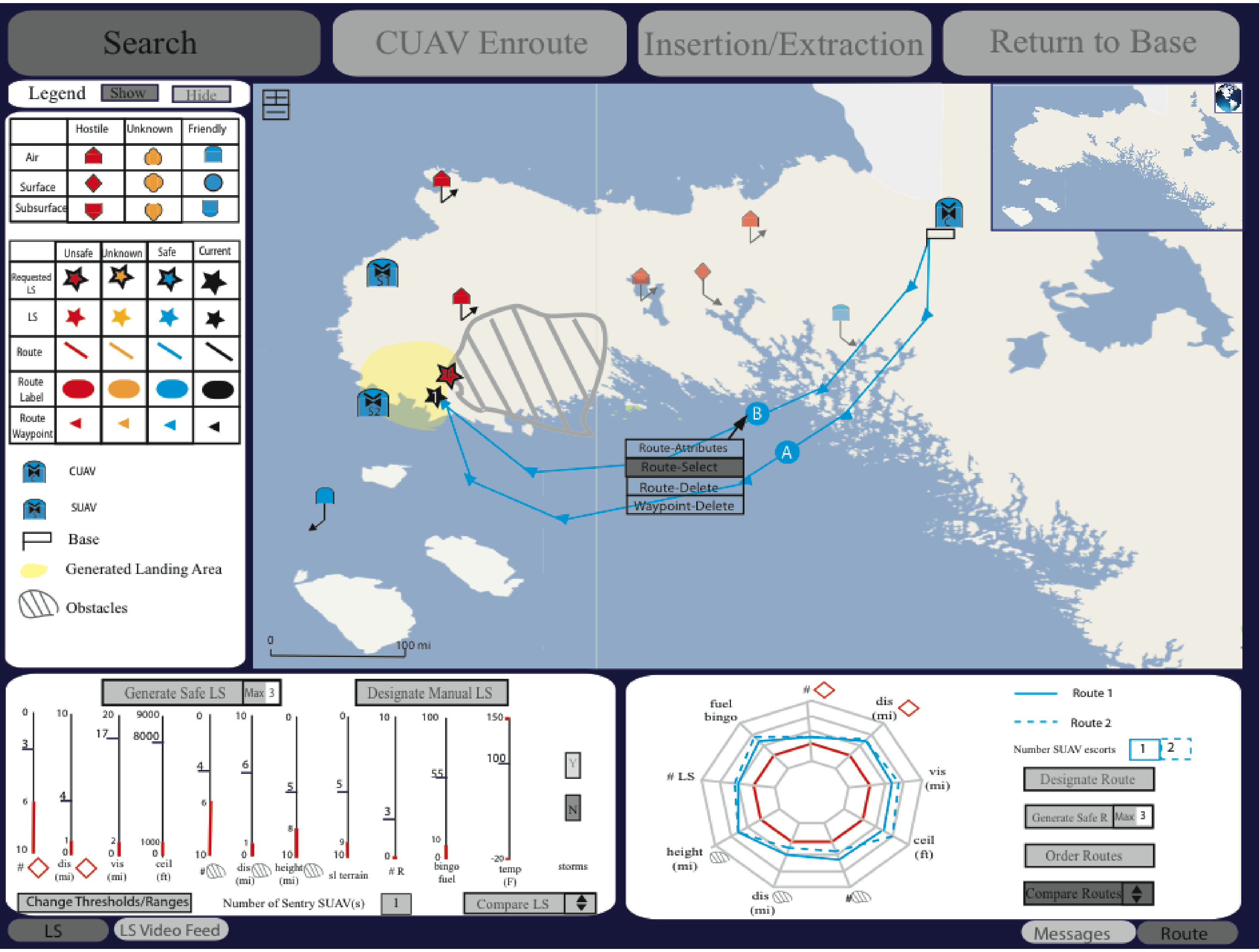


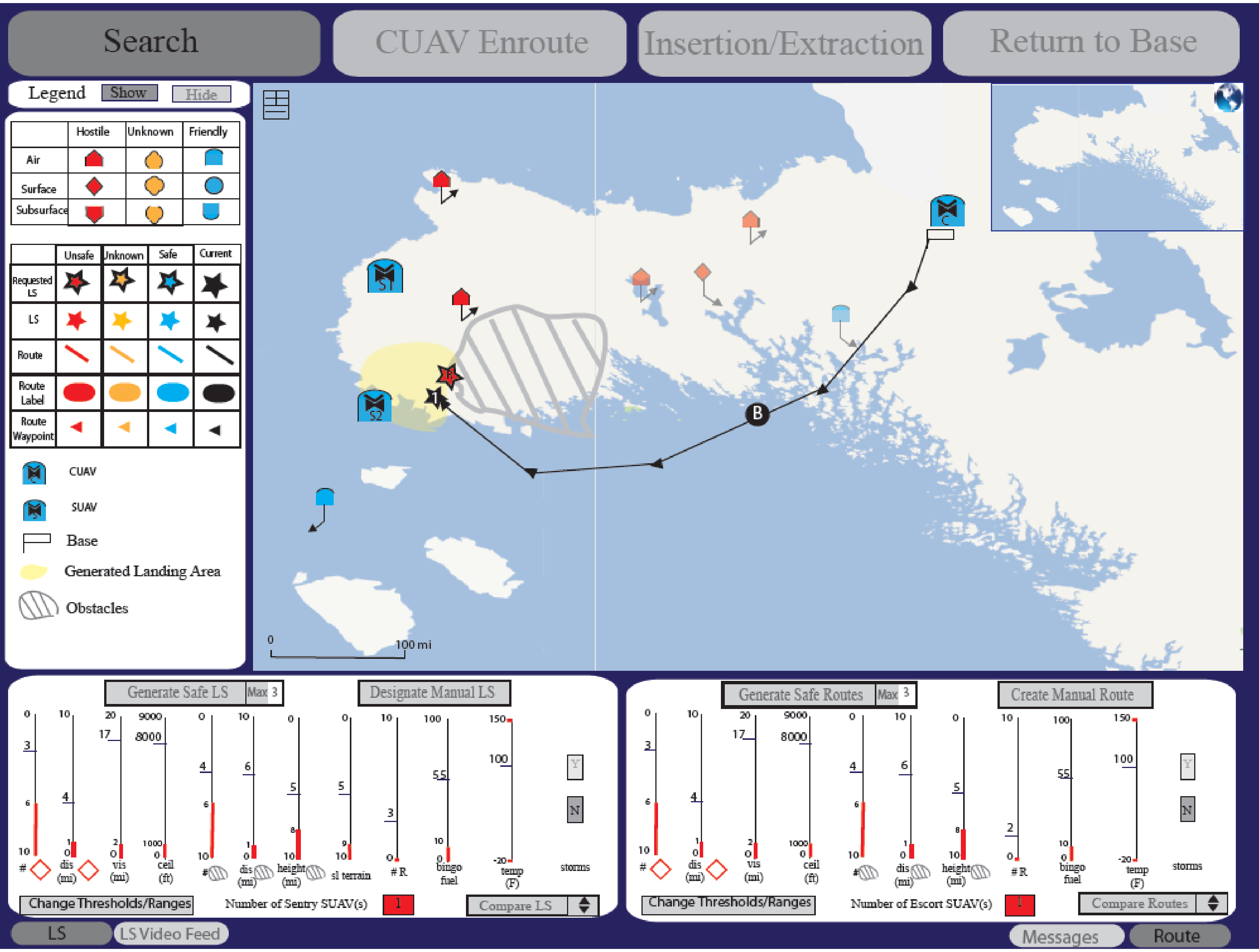
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
LS-Attributes
LS-Designate
LS-Delete
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
storms
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Order Routes
Compare Routes
Best
Worst
Route Ordering
LS
LS Video Feed
Messages
Route



Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
LS-Attributes
LS-Designate
LS-Delete
A
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Y
N
storms
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Designate Route
Generate Safe R
Max 3
Order Routes
Compare Routes
Best
B
A
Worst
Route Ordering
LS
LS Video Feed
Messages
Route

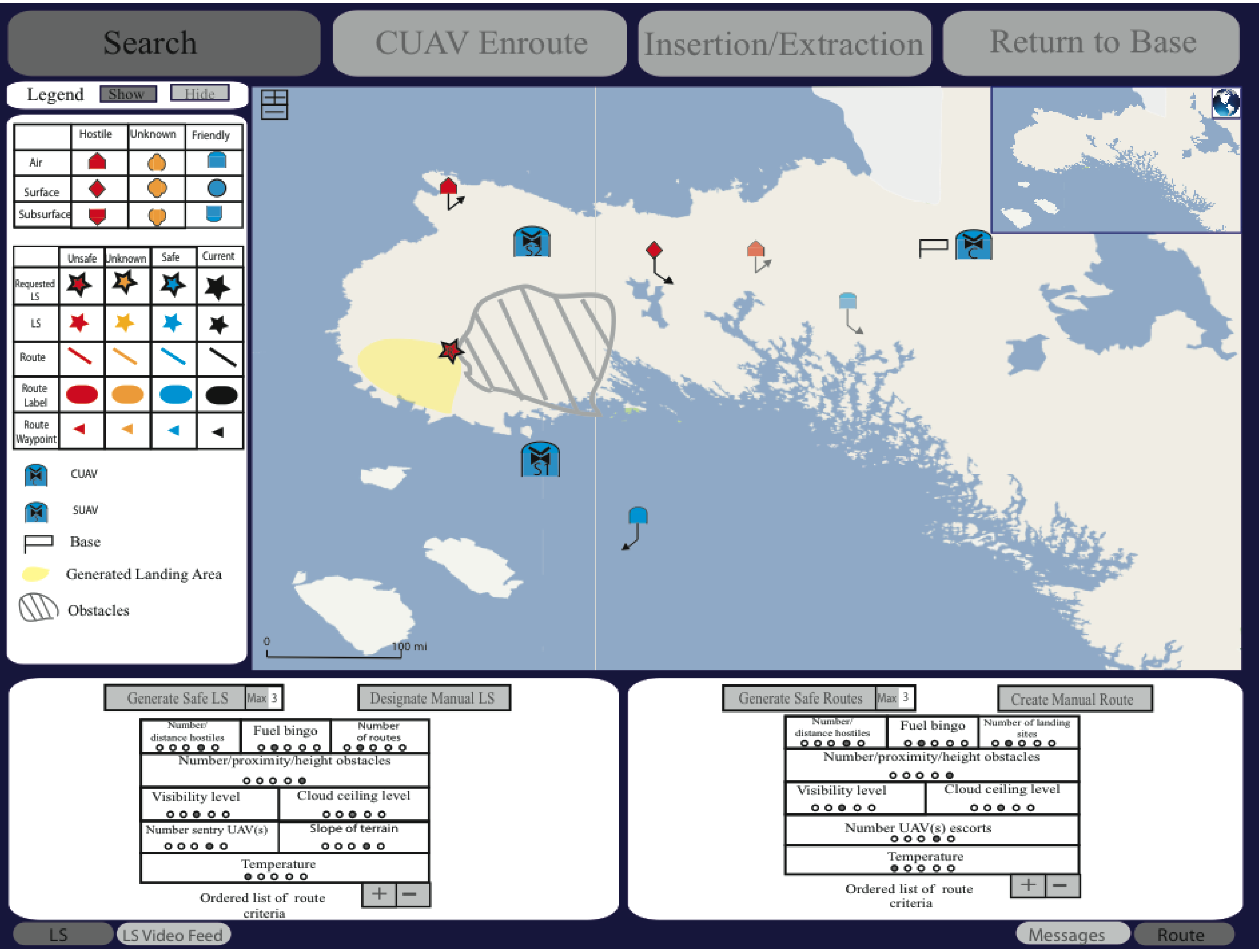

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
A
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi)
vis (mi)
ceil (ft)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
fuel bingo
# LS
height (mi)
dis (mi)
vis (mi)
ceil (ft)
Route 1
Route 2
Number SUAV escorts
1
2
Designate Route
Generate Safe R
Max 3
Order Routes
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Route-Attributes
Route-Select
Route-Delete
Waypoint-Delete
100 mi
Generate Safe LS
Max 3
Designate Manual LS
sl terrain
# R
bingo fuel
temp (F)
storms
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
fuel bingo
# LS
height (mi)
dis (mi)
vis (mi)
ceil (ft)
Route 1
Route 2
Number SUAV escorts
Designate Route
Generate Safe R
Order Routes
Compare Routes
LS
LS Video Feed
Messages
Route

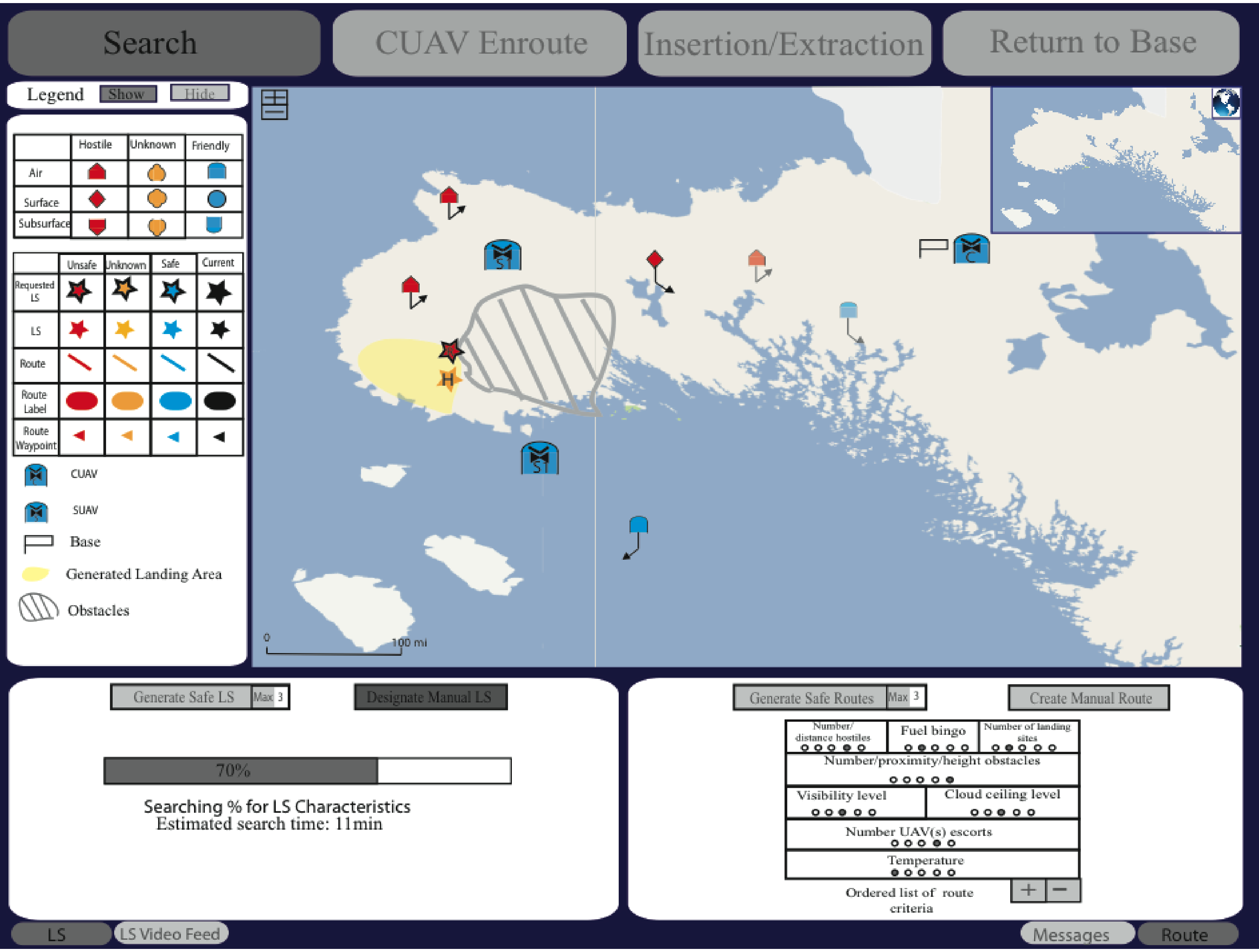


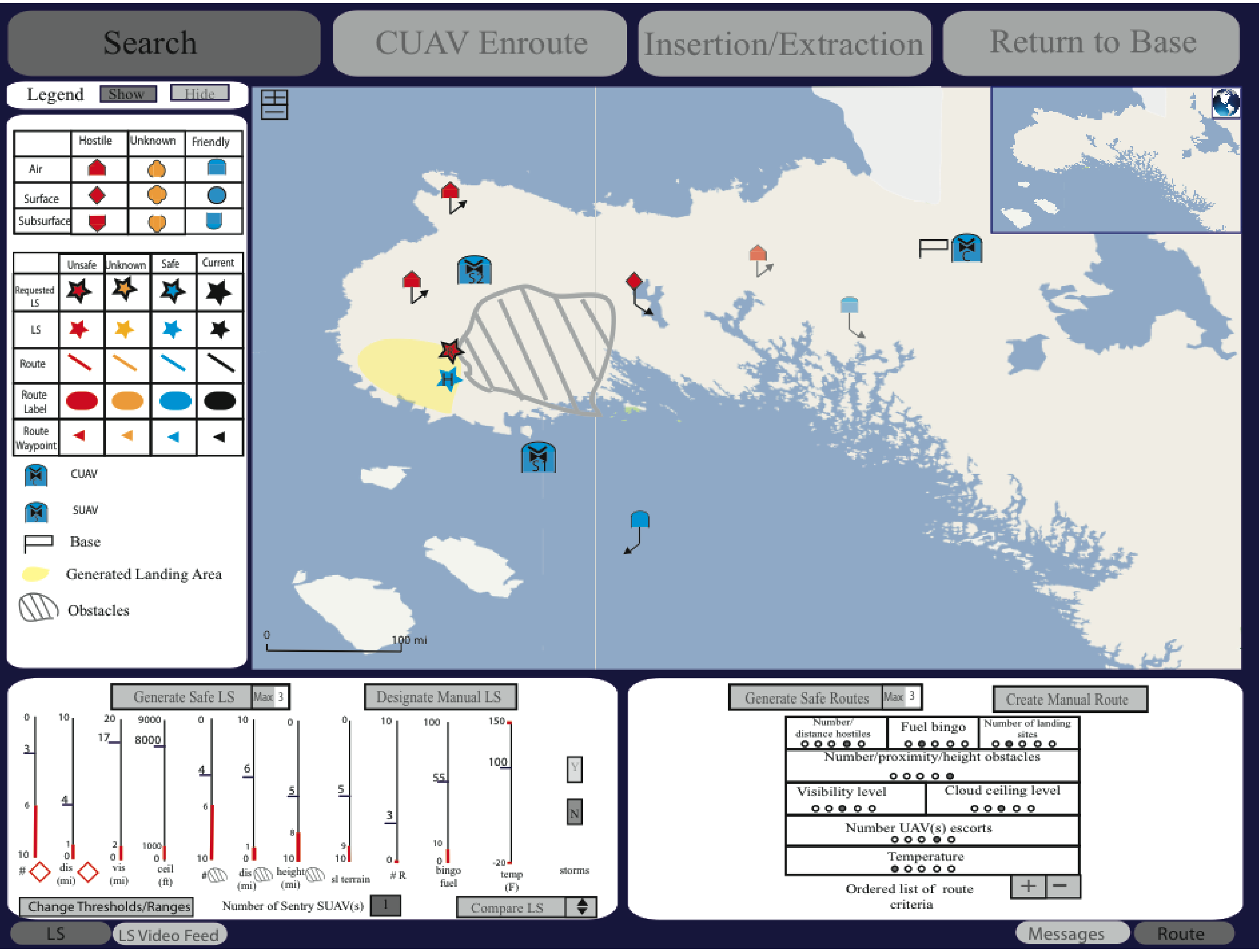
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

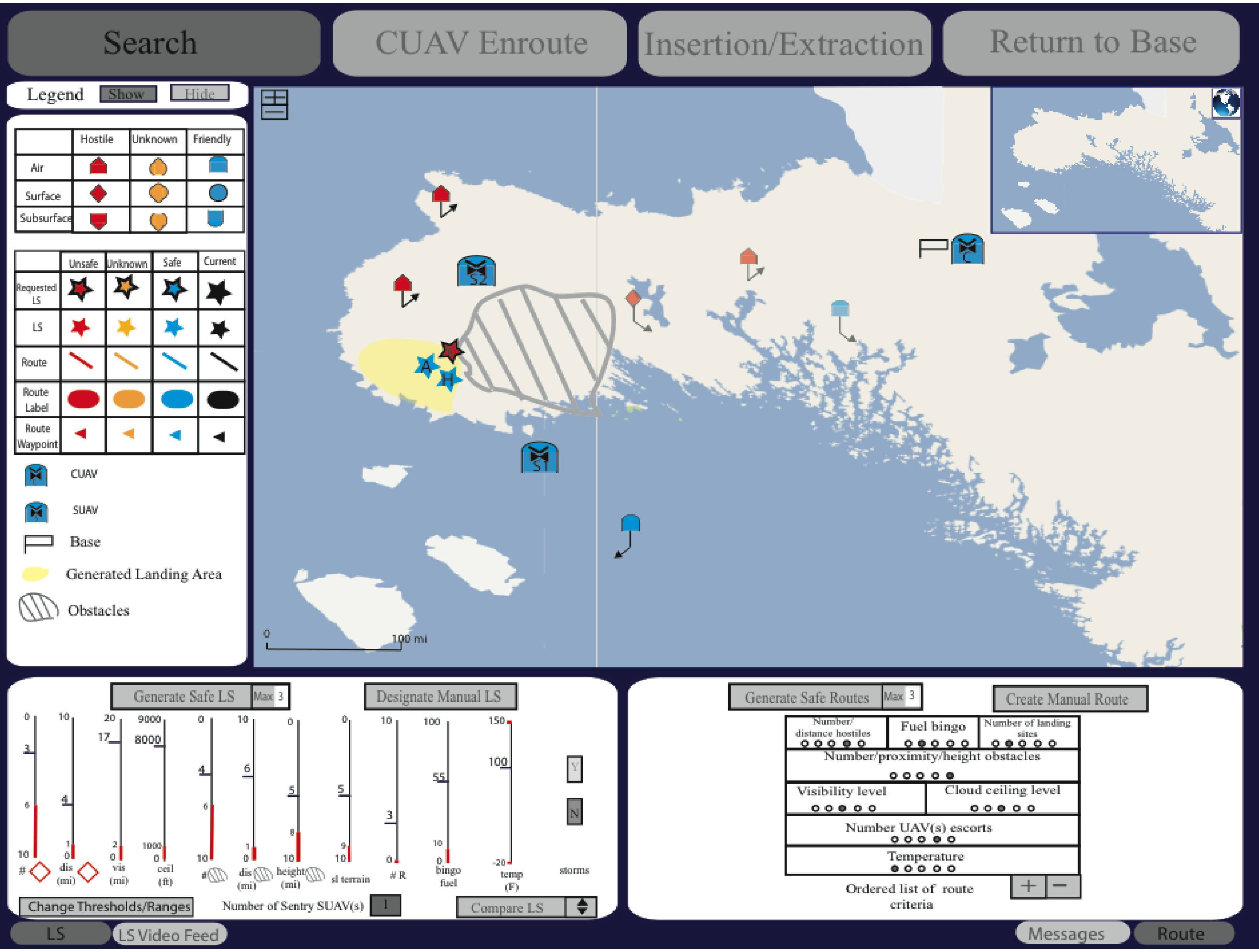
# Goal: Generate a Landing Site and Route



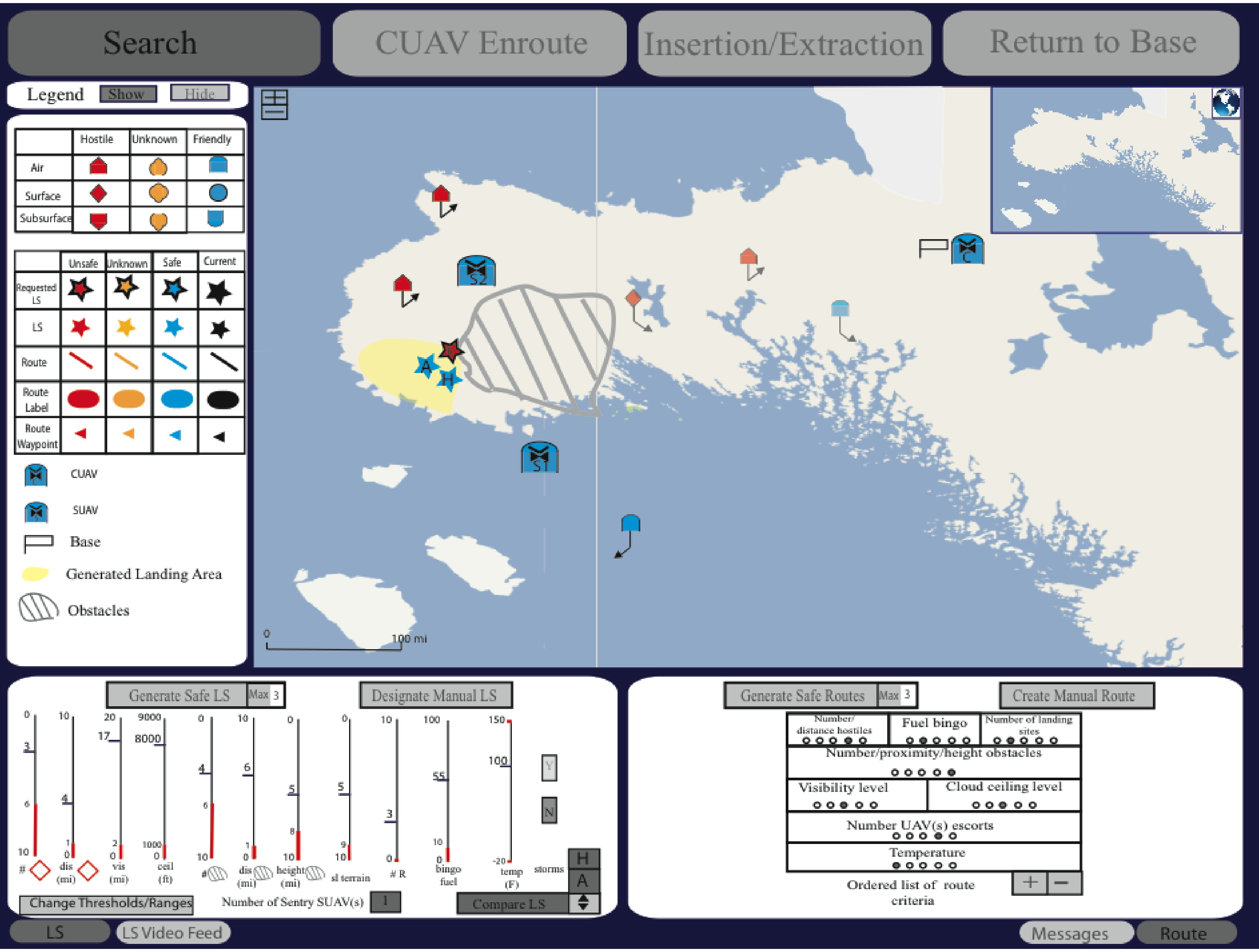
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S2
S1
C
0
100 mi
Generate Safe LS
Max
3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of route criteria
Generate Safe Routes
Max
3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

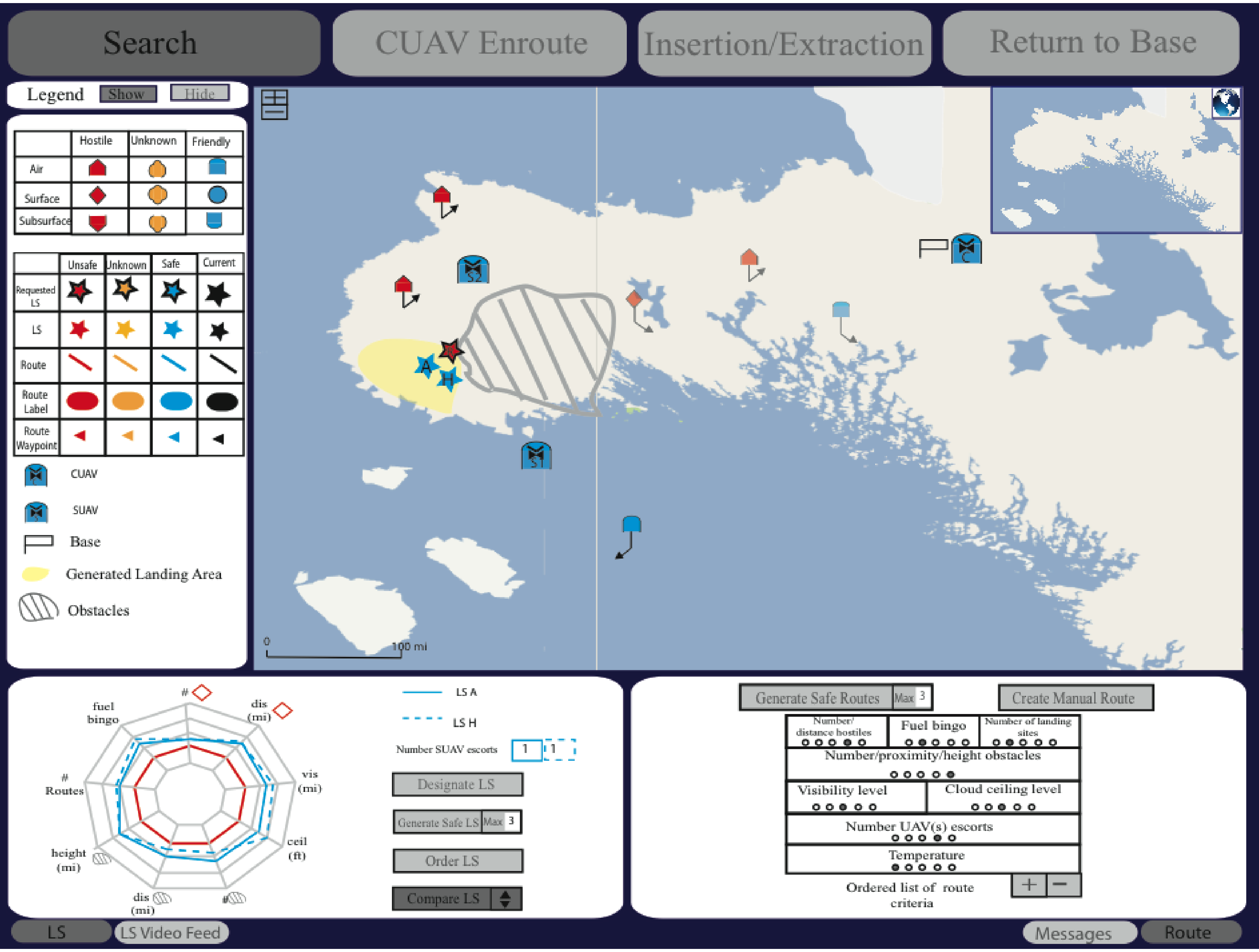

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
70%
Searching % for LS Characteristics
Estimated search time: 11min
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
+
−
LS
LS Video Feed
Messages
Route

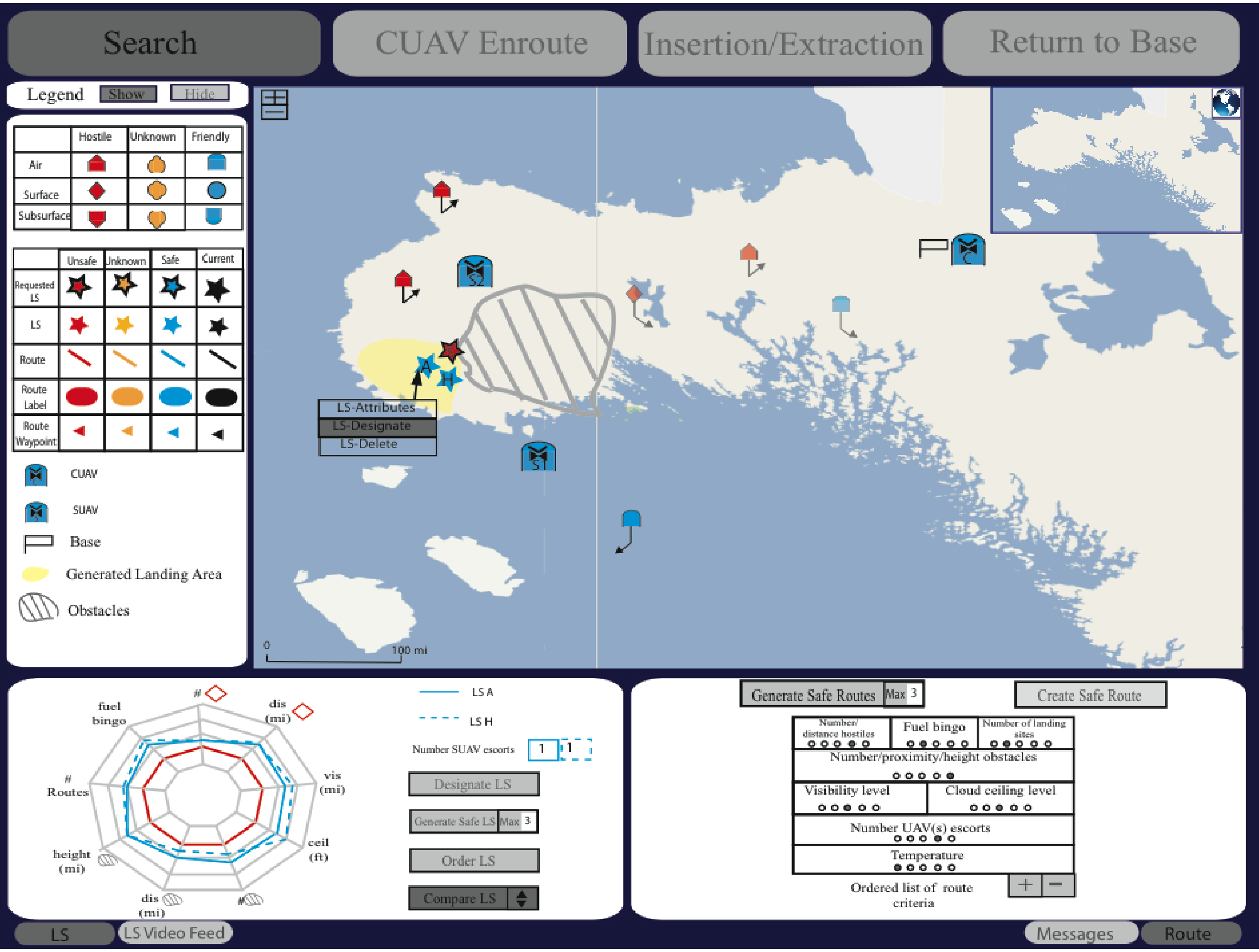

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi)
vis (mi)
ceil (ft)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route



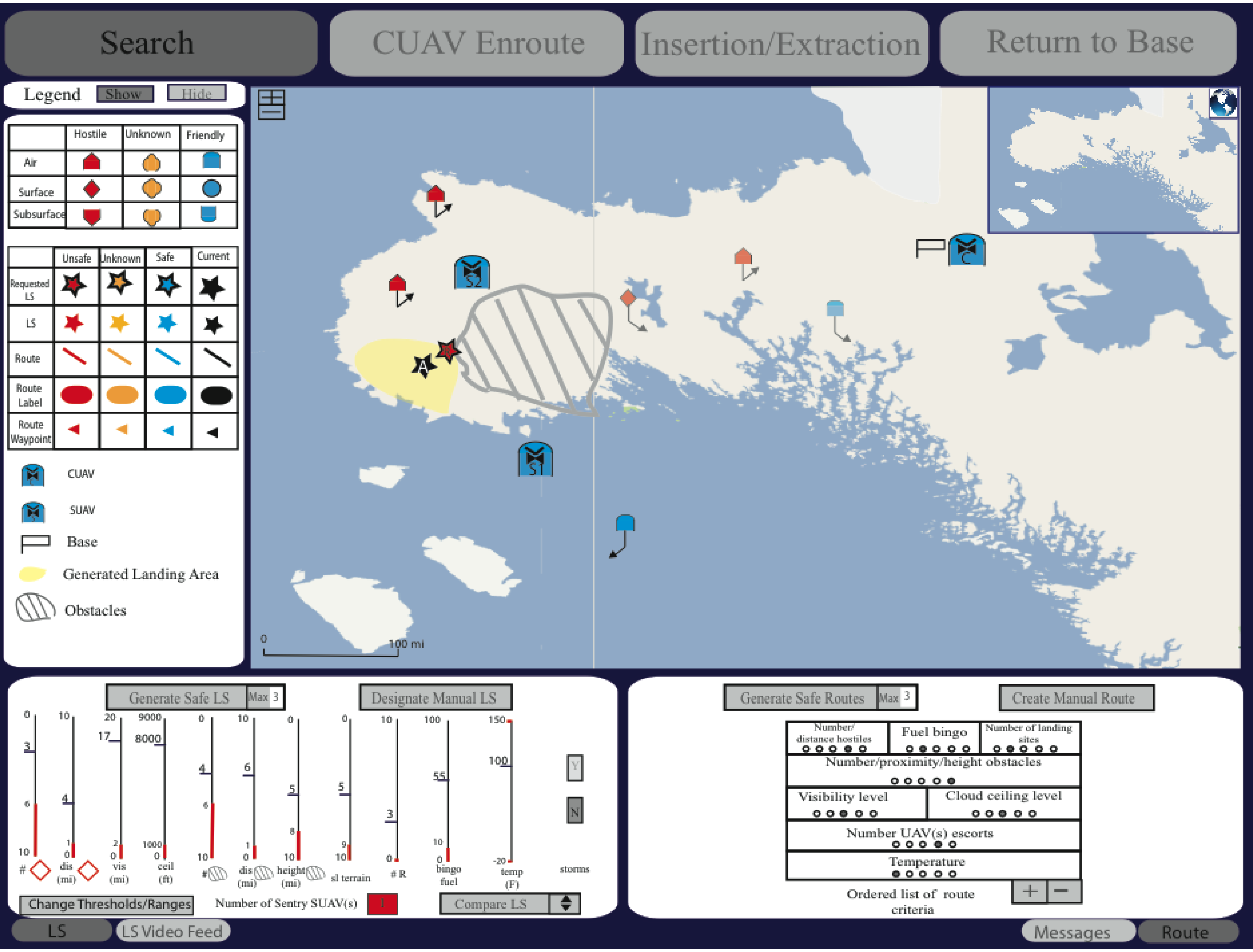
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S2
S1
C
A
H
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

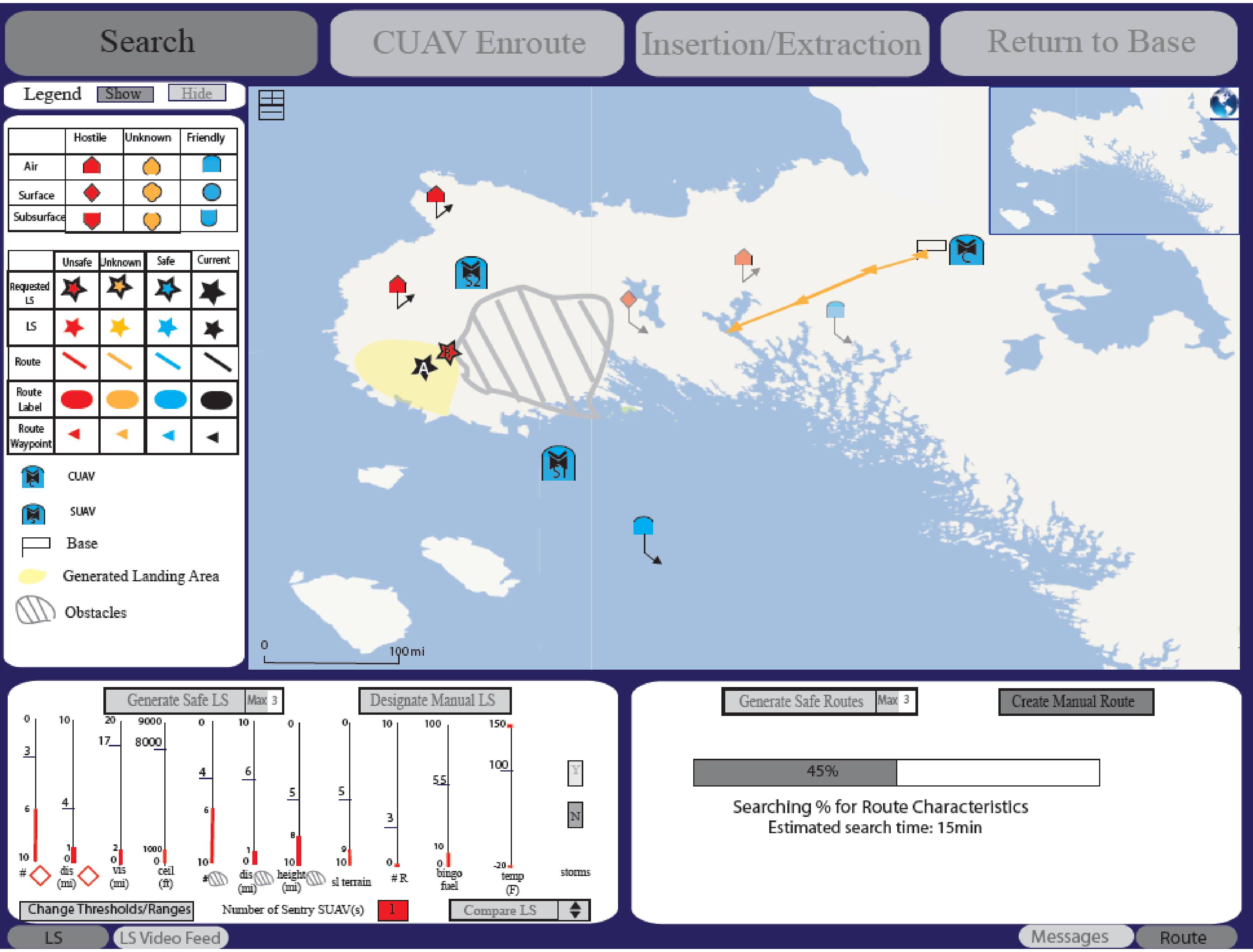

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S2
S1
C
A
H
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Y
N
H
A
storms
# R
bingo fuel
temp (F)
sl terrain
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
A
H
S2
S1
C
# 
dis (mi)
vis (mi)
ceil (ft)
# 
dis (mi)
height (mi)
# Routes
fuel bingo
LS A
LS H
Number SUAV escorts
1
1
Designate LS
Generate Safe LS
Max
3
Order LS
Compare LS
Generate Safe Routes
Max
3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
+
−
LS
LS Video Feed
Messages
Route

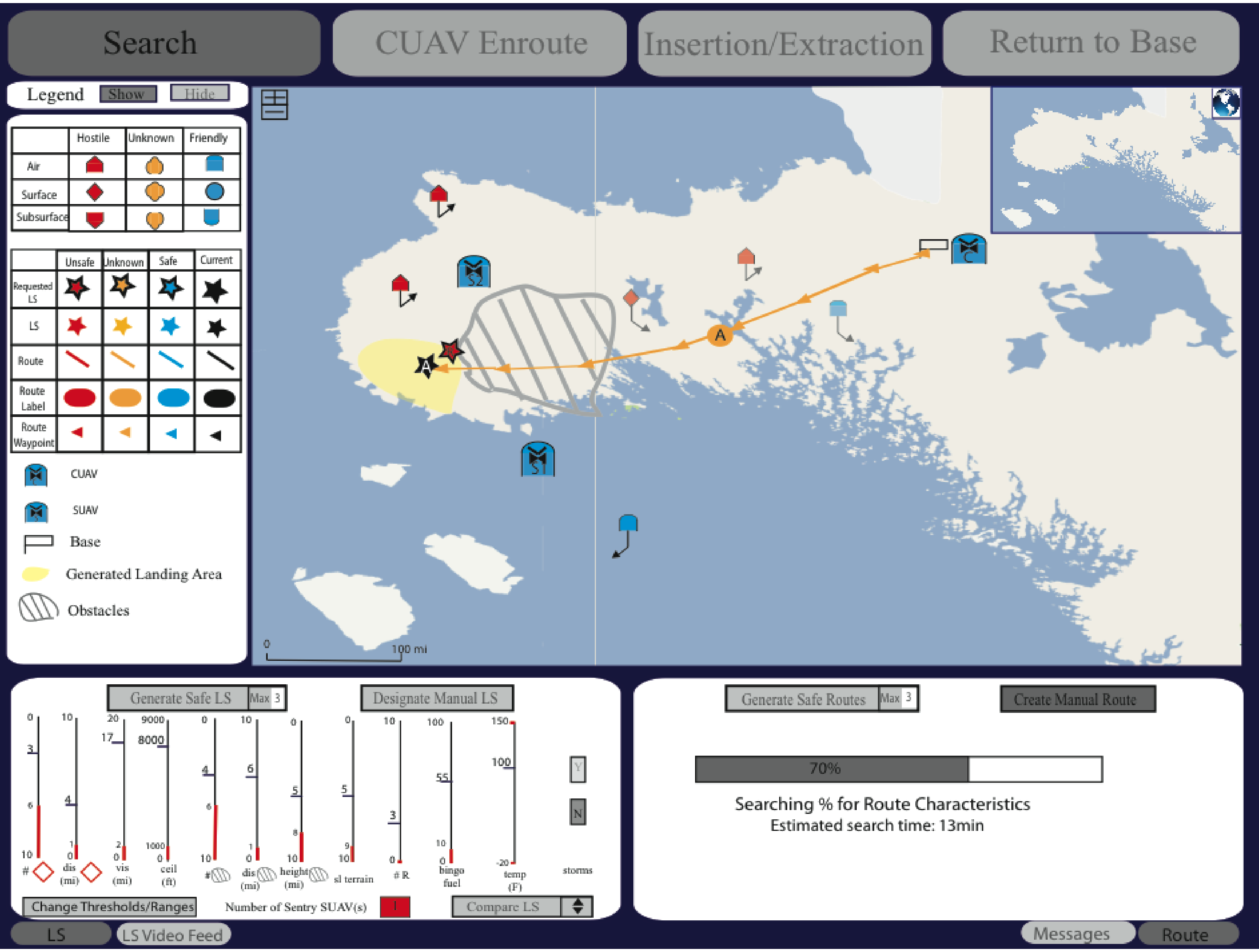


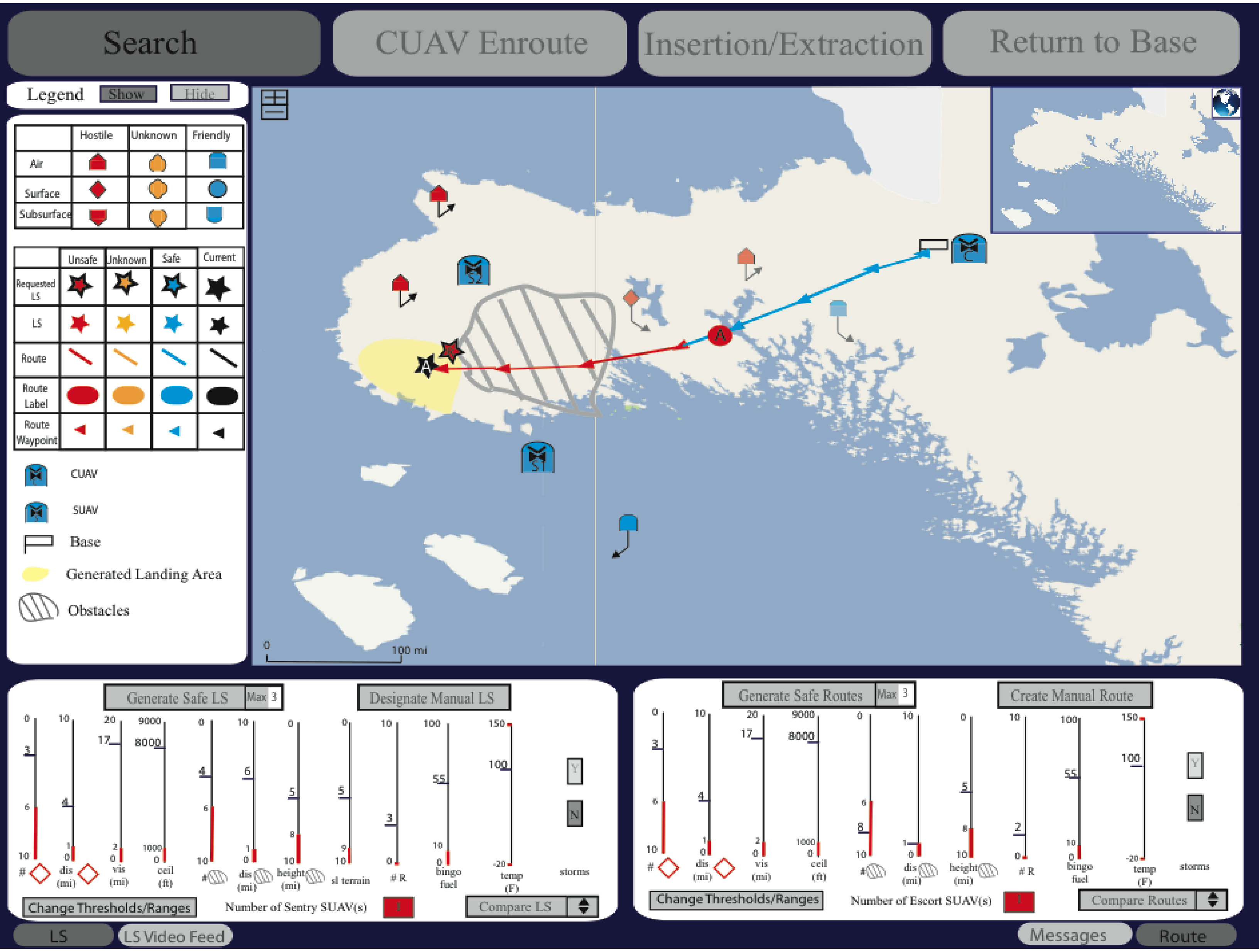
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
LS-Attributes
LS-Designate
LS-Delete
0
100 mi
LS A
LS H
Number SUAV escorts
Designate LS
Generate Safe LS
Max
Order LS
Compare LS
Generate Safe Routes
Create Safe Route
Number/distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

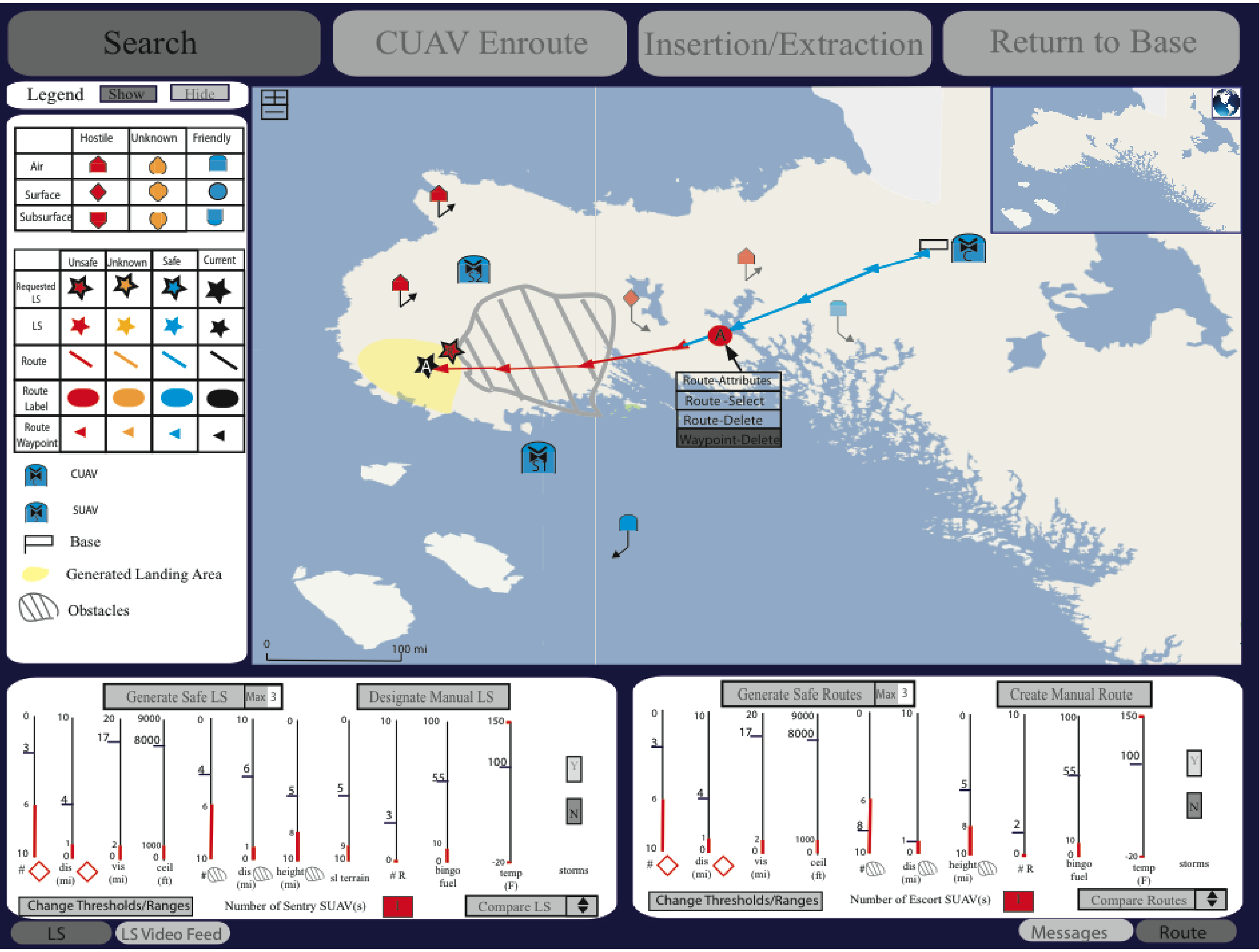

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S2
S1
C
A
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
storms
Y
N
LS
LS Video Feed
Generate Safe Routes
Max 3
Create Manual Route
Fuel bingo
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
Messages
Route

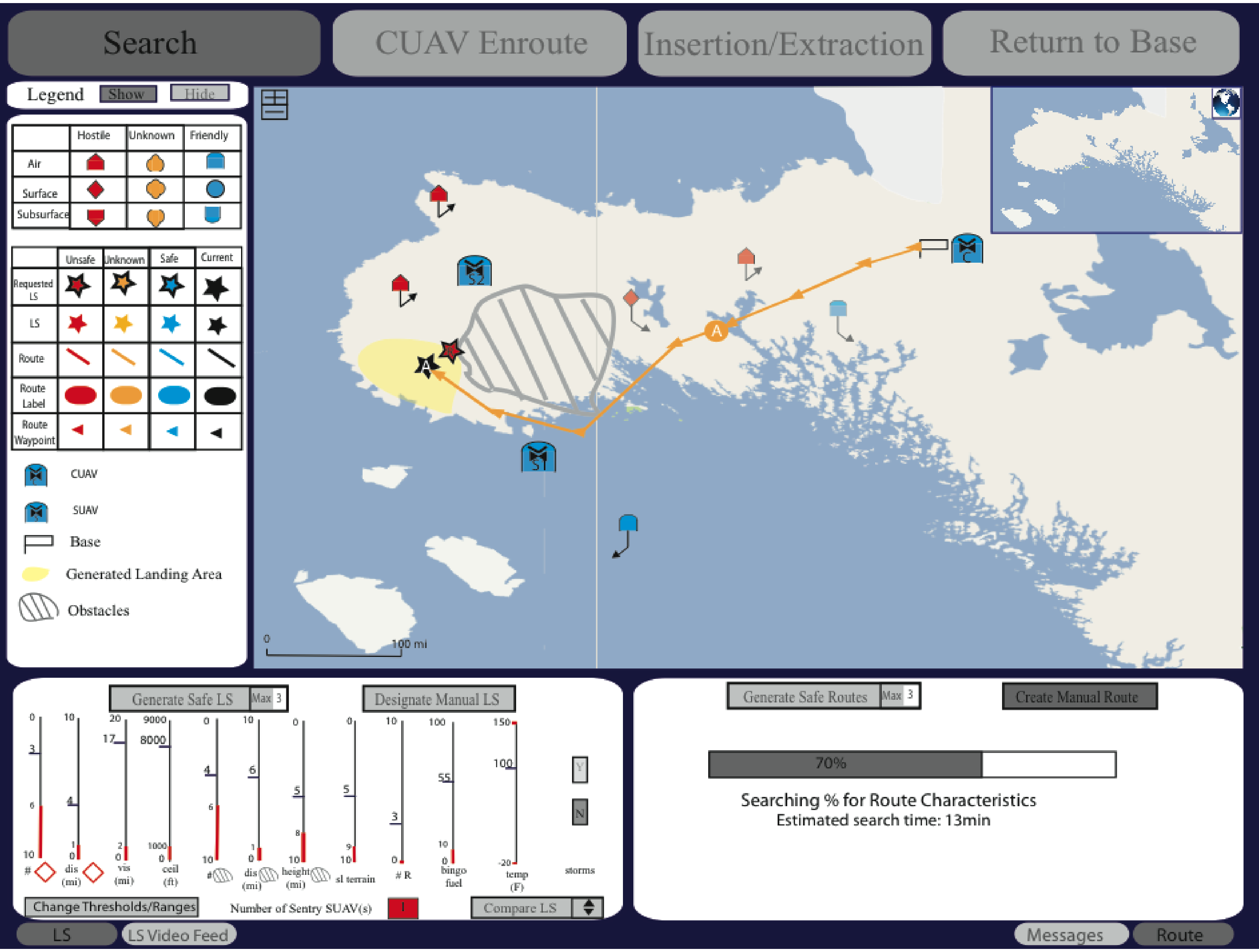


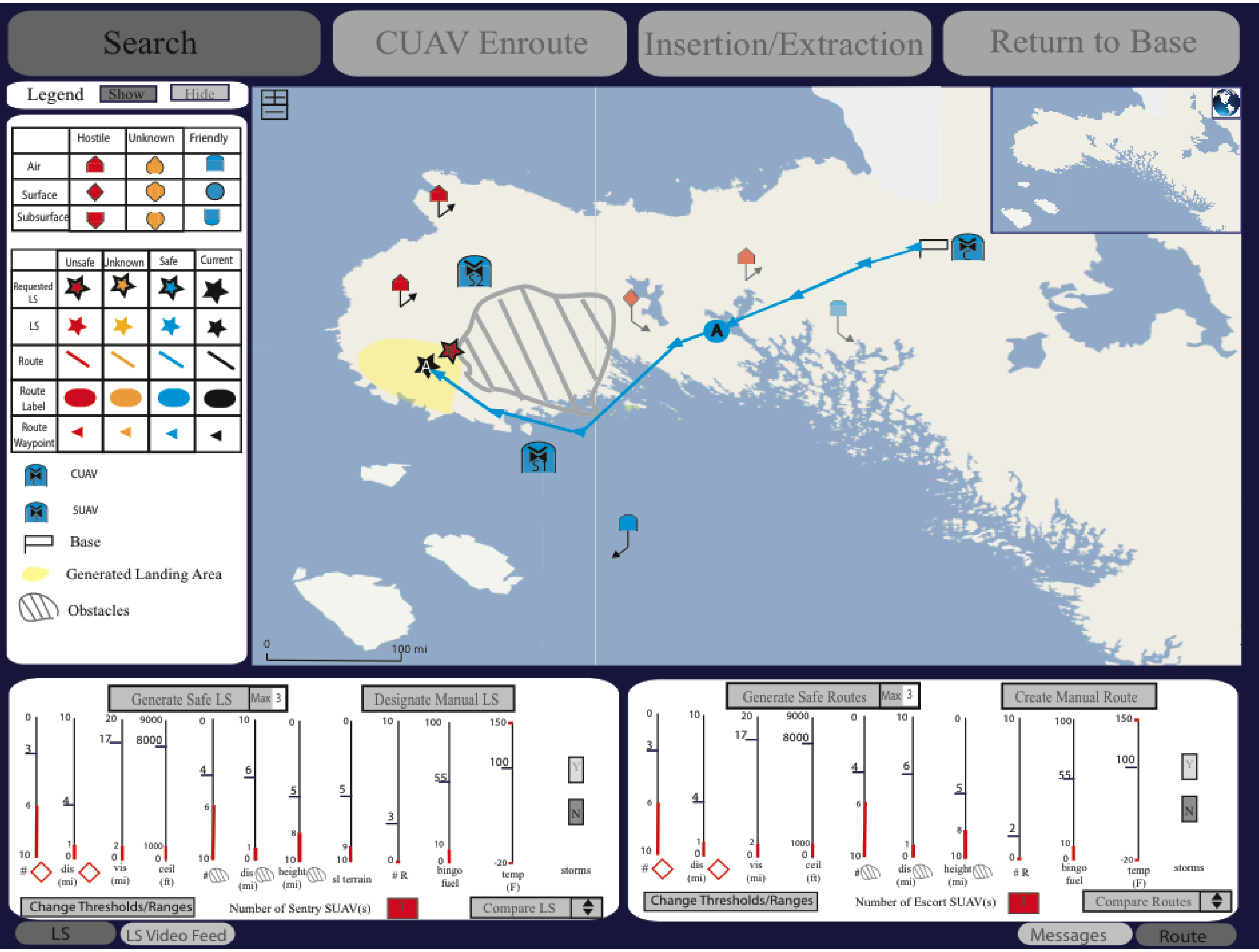
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# 
dis (mi)
vis (mi)
ceil (ft)
dis (mi)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
45%
Searching % for Route Characteristics
Estimated search time: 15min
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S2
S1
C
A
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi) vis (mi) ceil (ft) dis (mi) height (mi) sl terrain # R bingo fuel temp (F) storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
70%
Searching % for Route Characteristics
Estimated search time: 13min
LS
LS Video Feed
Messages
Route

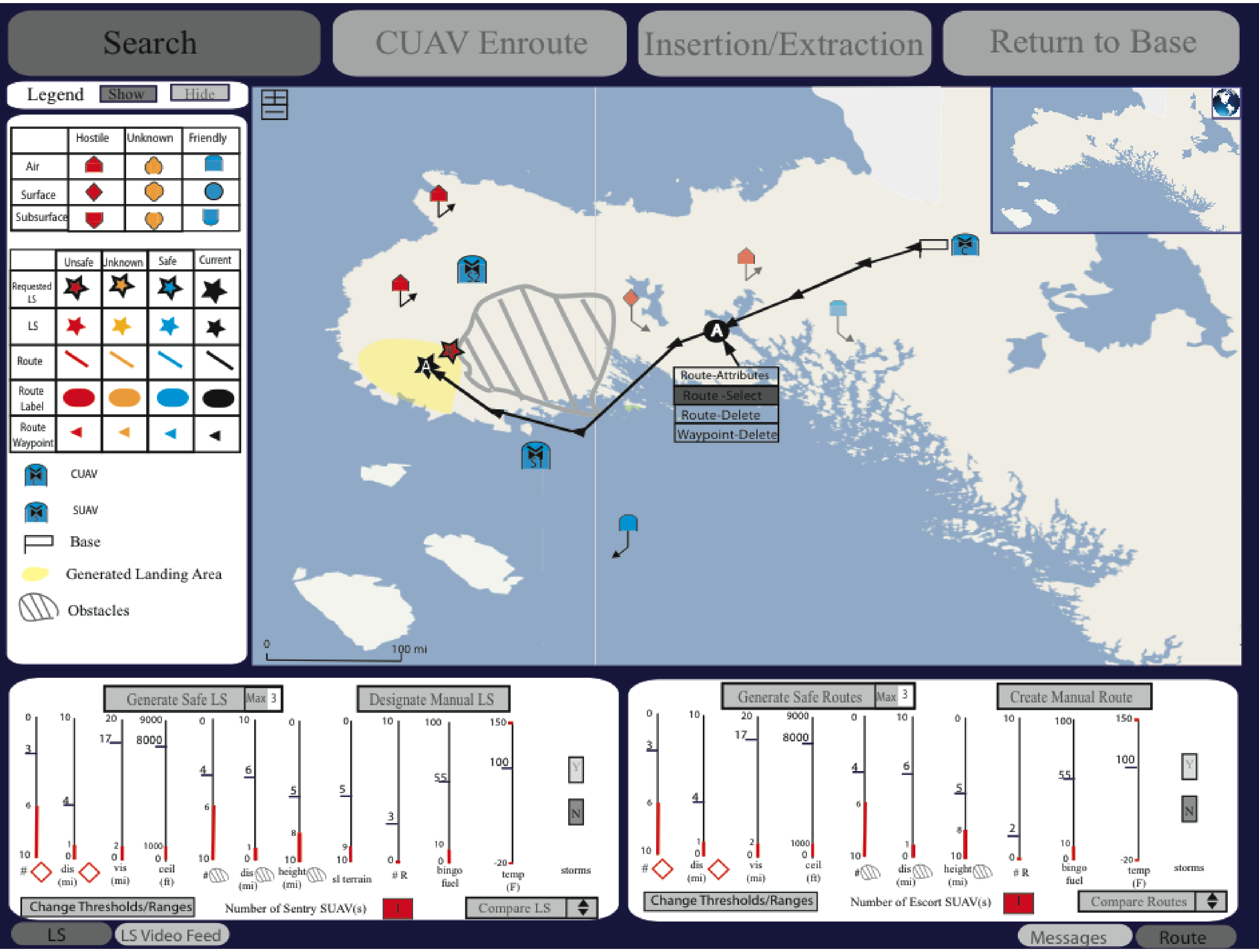

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
storms
Generate Safe Routes
Max 3
Create Manual Route
Change Thresholds/Ranges
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Route-Attributes
Route -Select
Route-Delete
Waypoint-Delete
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi) vis (mi) ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
70%
Searching % for Route Characteristics
Estimated search time: 13min
LS
LS Video Feed
Messages
Route

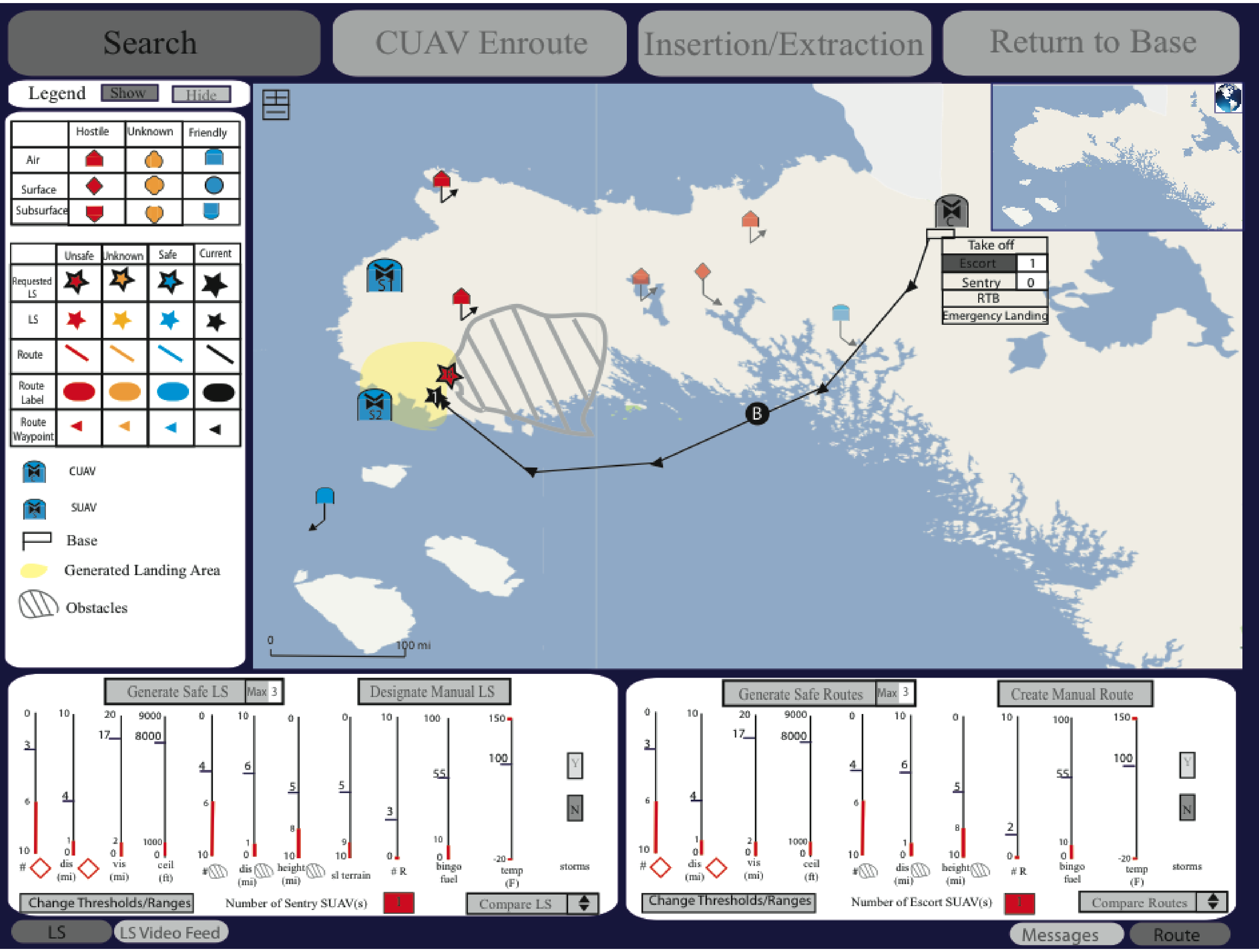


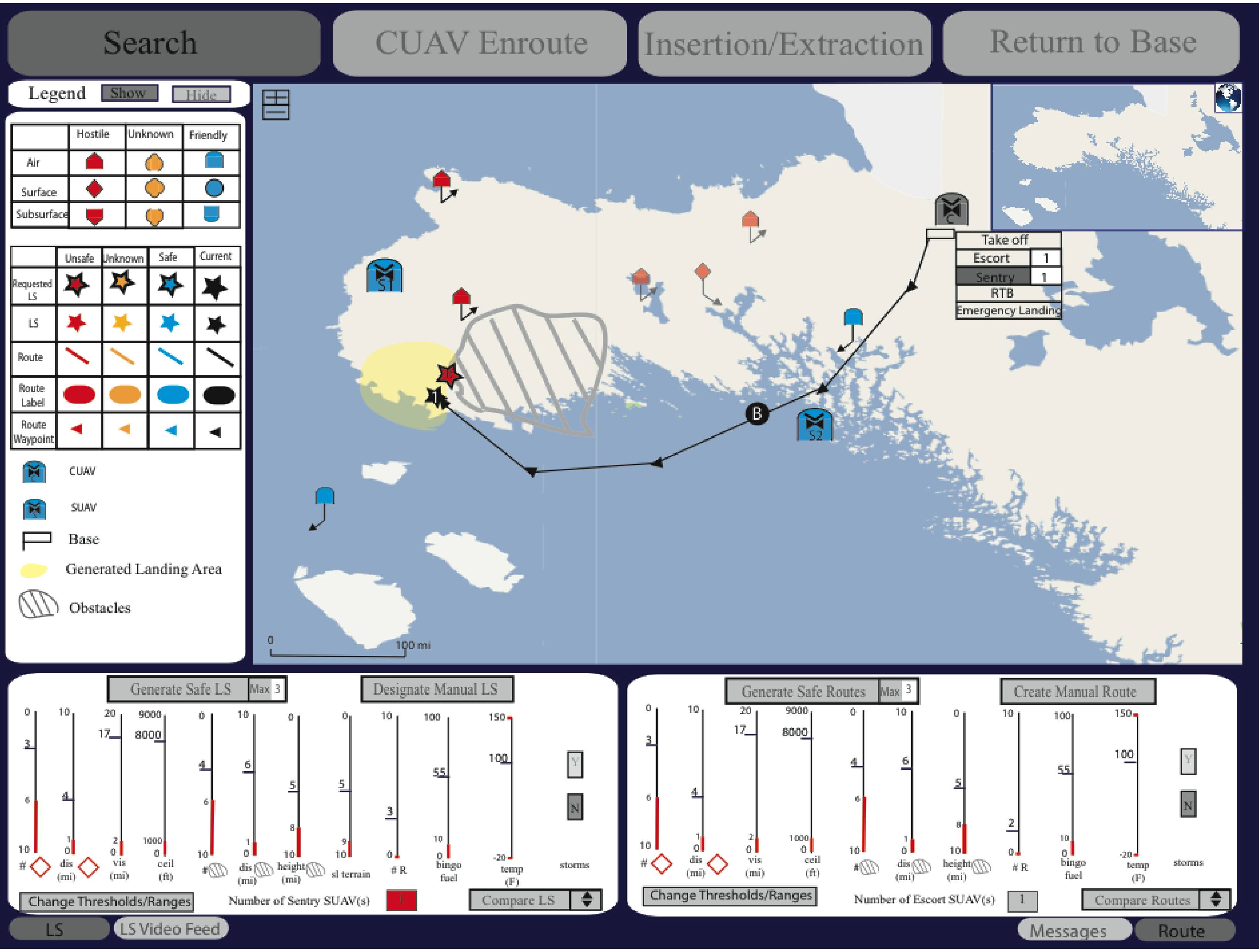
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
storms
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

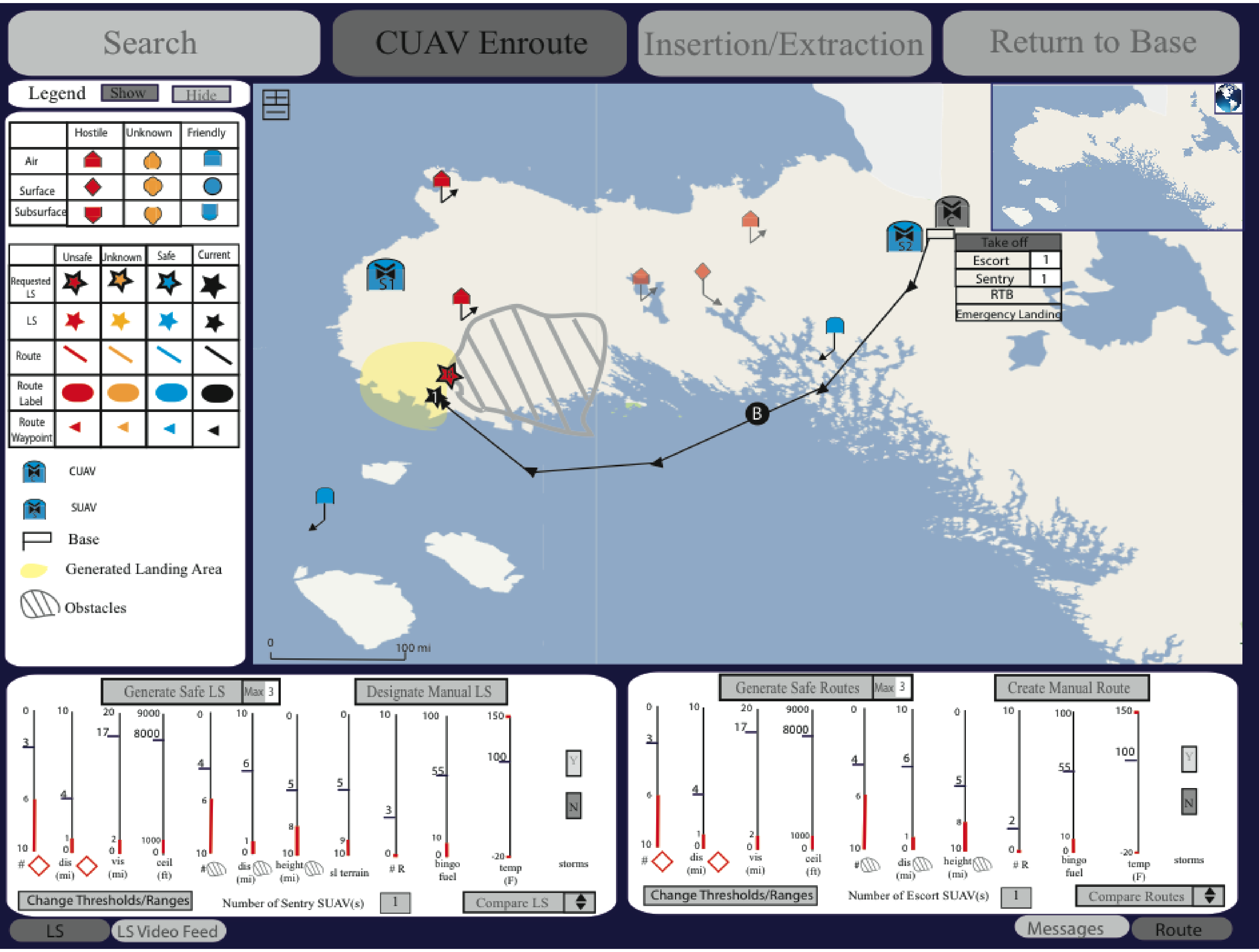


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Route-Attributes
Route -Select
Route-Delete
Waypoint-Delete
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

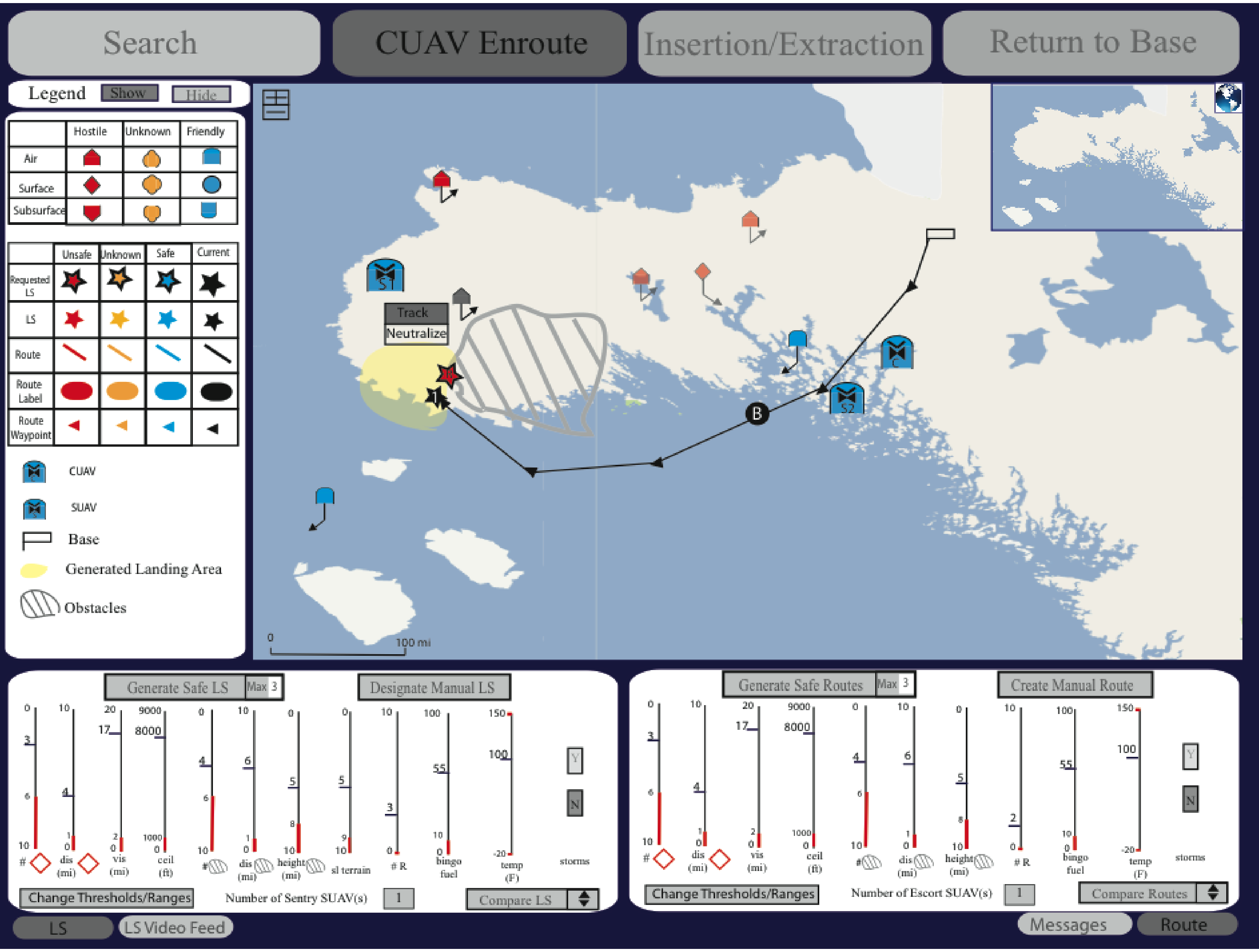
CUAV needs to be escorted by an SUAV to reach the landing area.

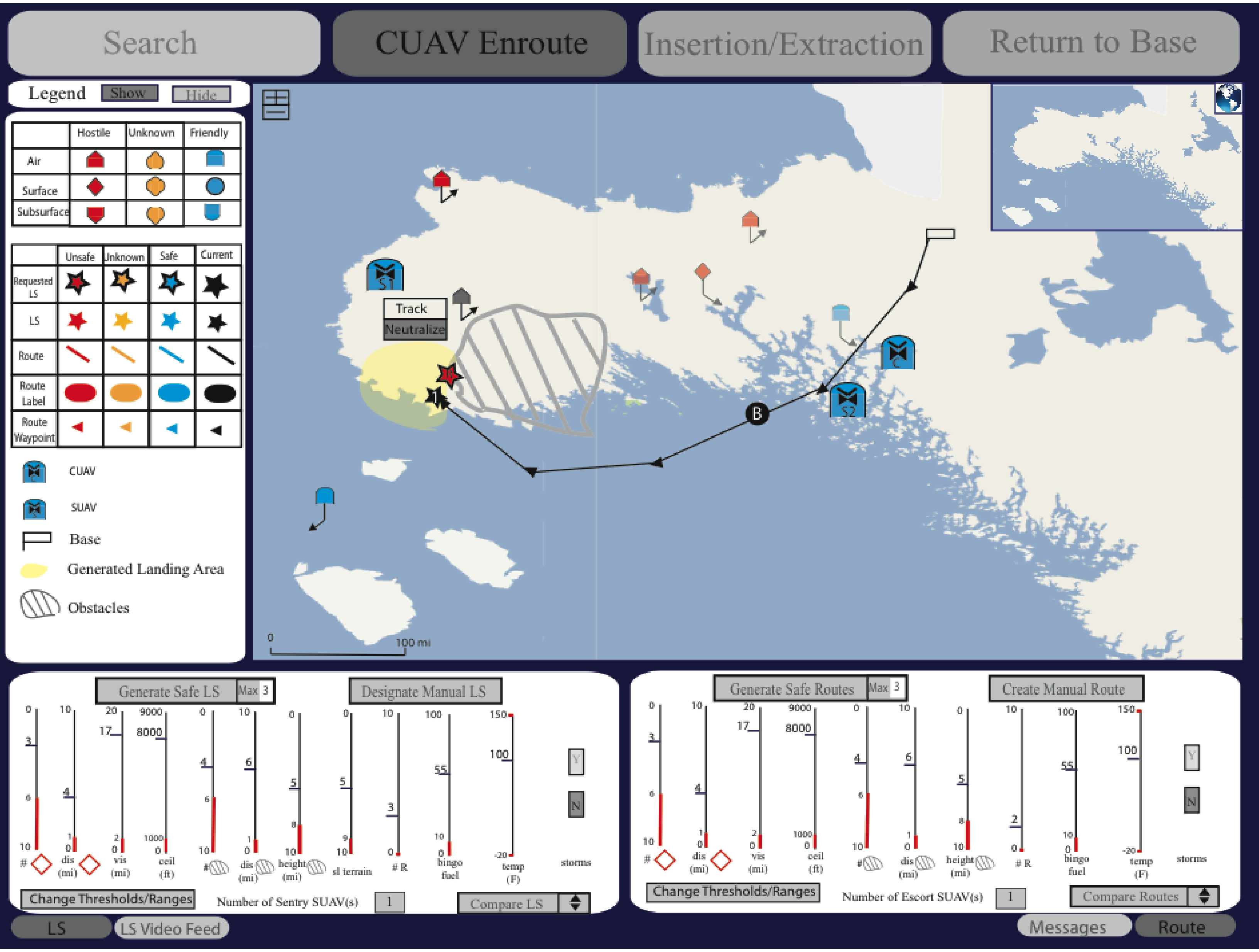

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Take off
Escort
1
Sentry
0
RTB
Emergency Landing
S1
S2
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Generate Safe Routes
Create Manual Route
# dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Number of Escort SUAV(s)
Compare LS
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Take off
Escort
Sentry
RTB
Emergency Landing
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Change Thresholds/Ranges
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

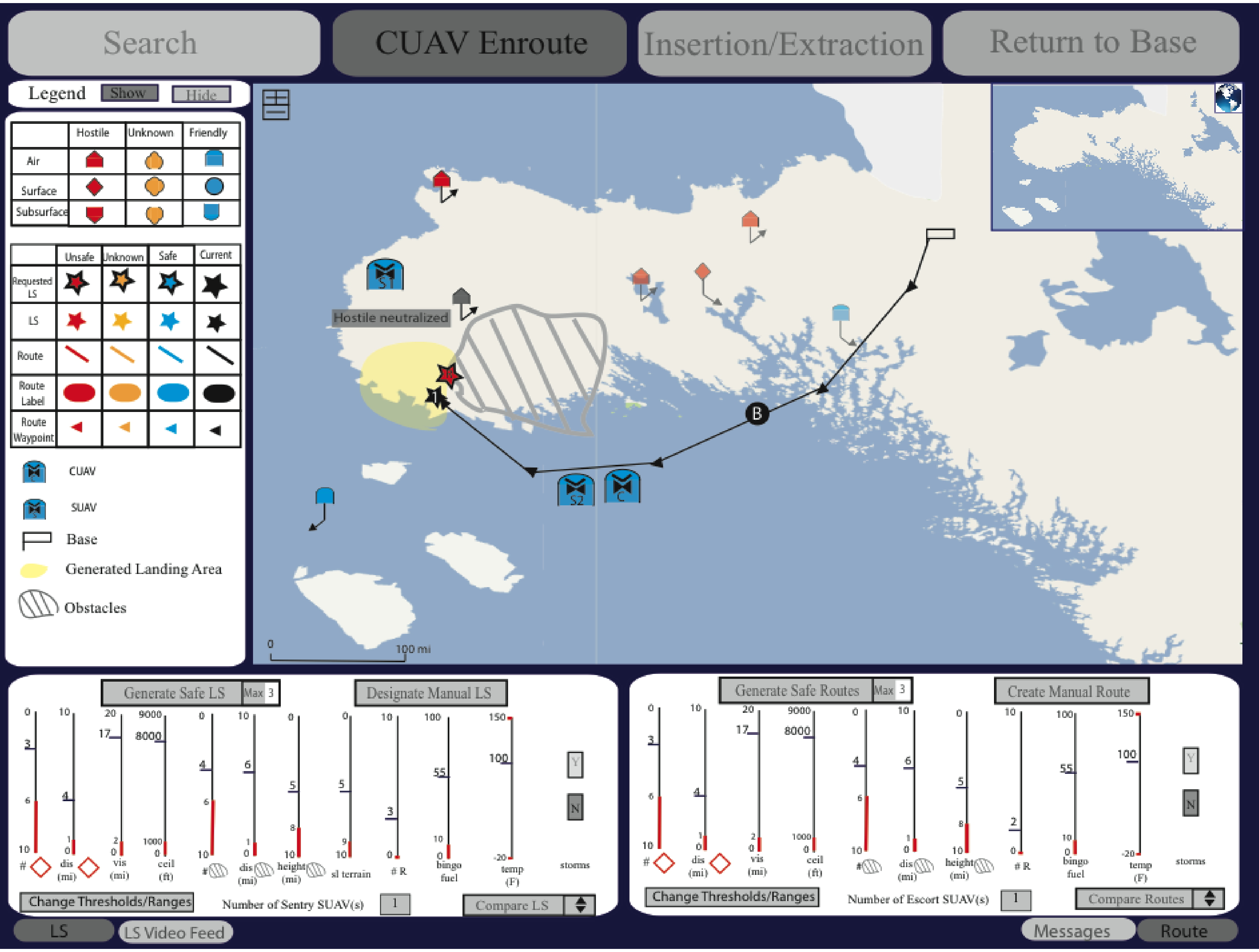


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
B
Take off
Escort 1
Sentry 1
RTB
Emergency Landing
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Create Manual Route
Change Thresholds/Ranges
Number of Escort SUAV(s)
Compare Routes
dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
LS
LS Video Feed
Messages
Route

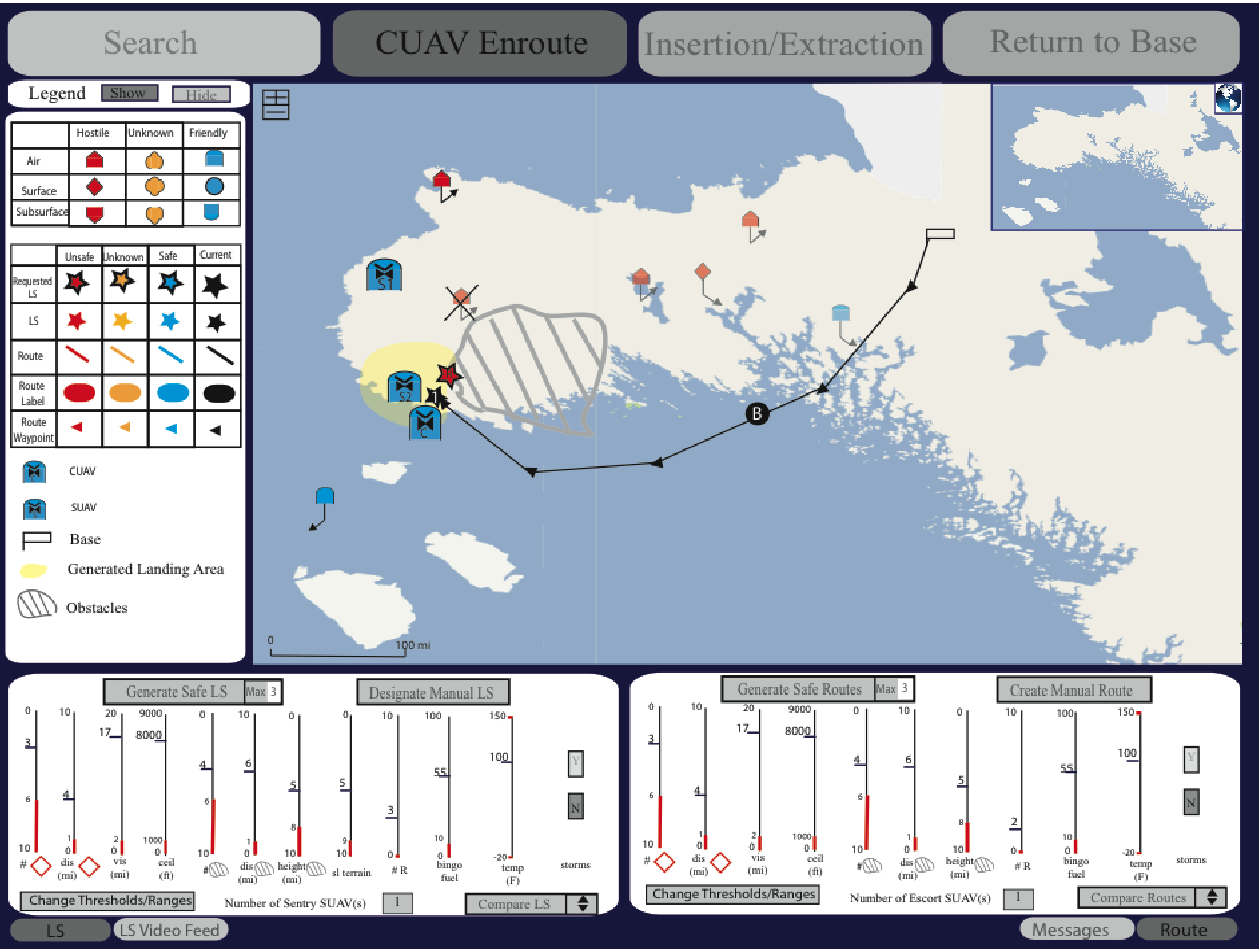

Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Track
Neutralize
S1
S2
C
B
1
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

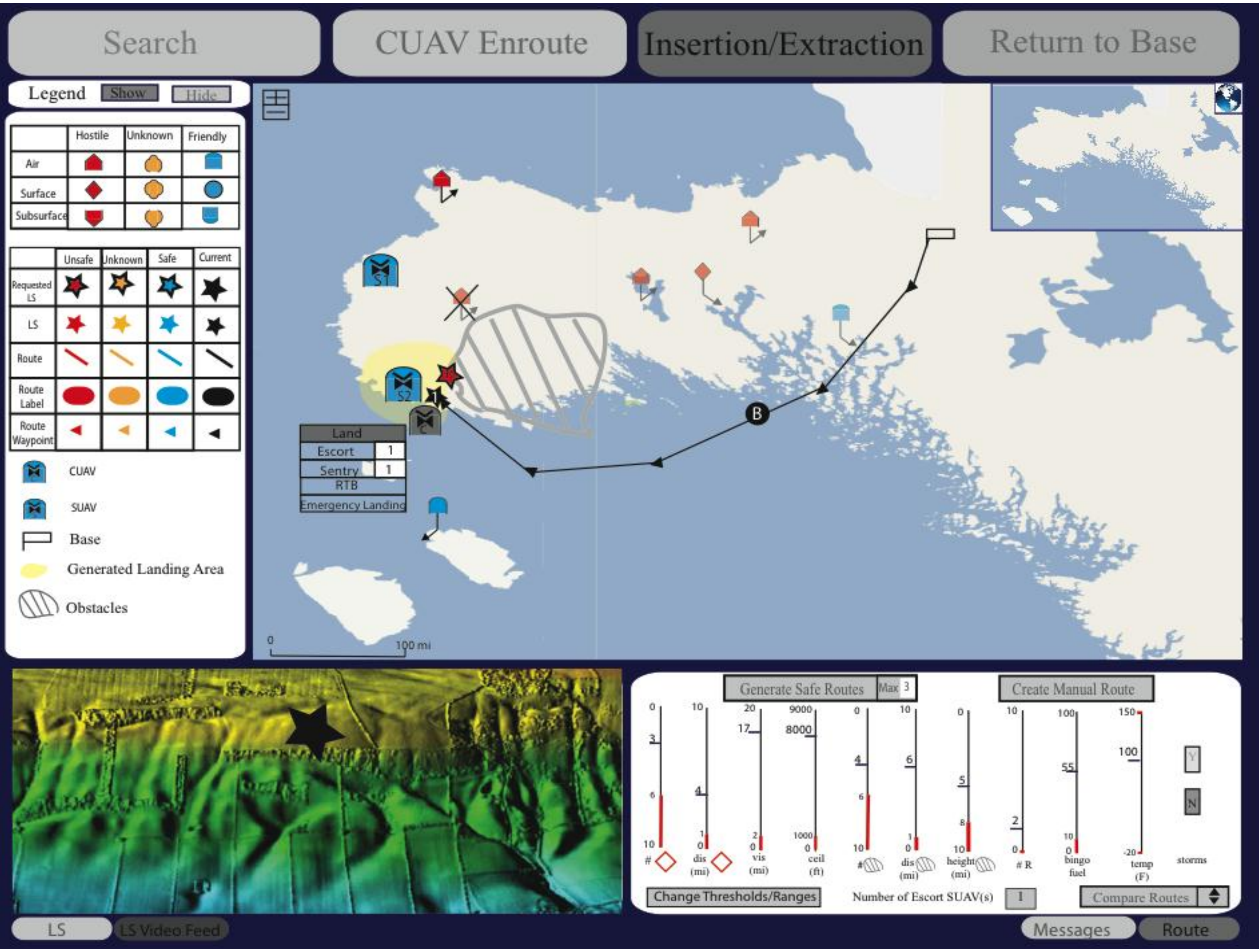


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Track
Neutralize
S1
S2
C
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

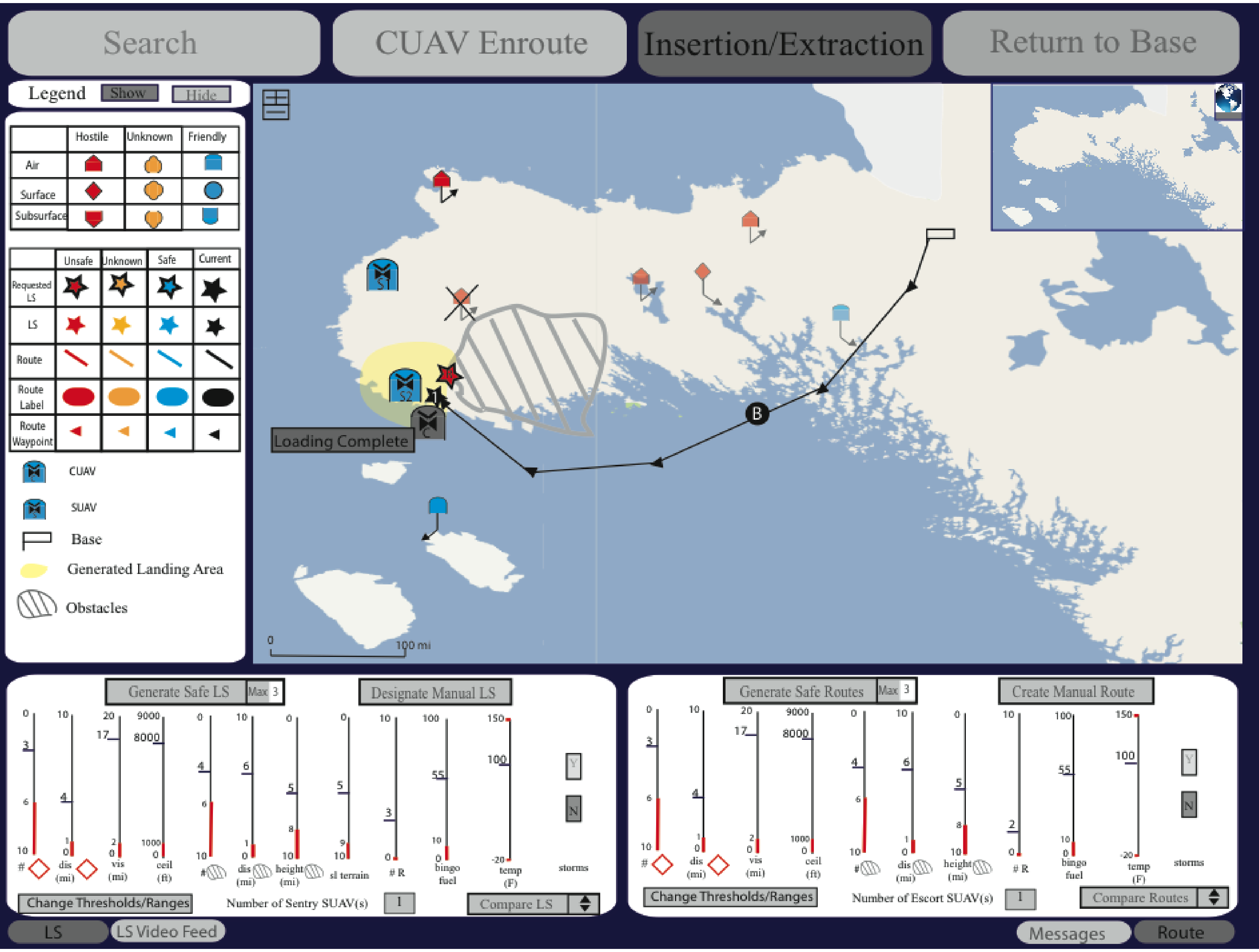


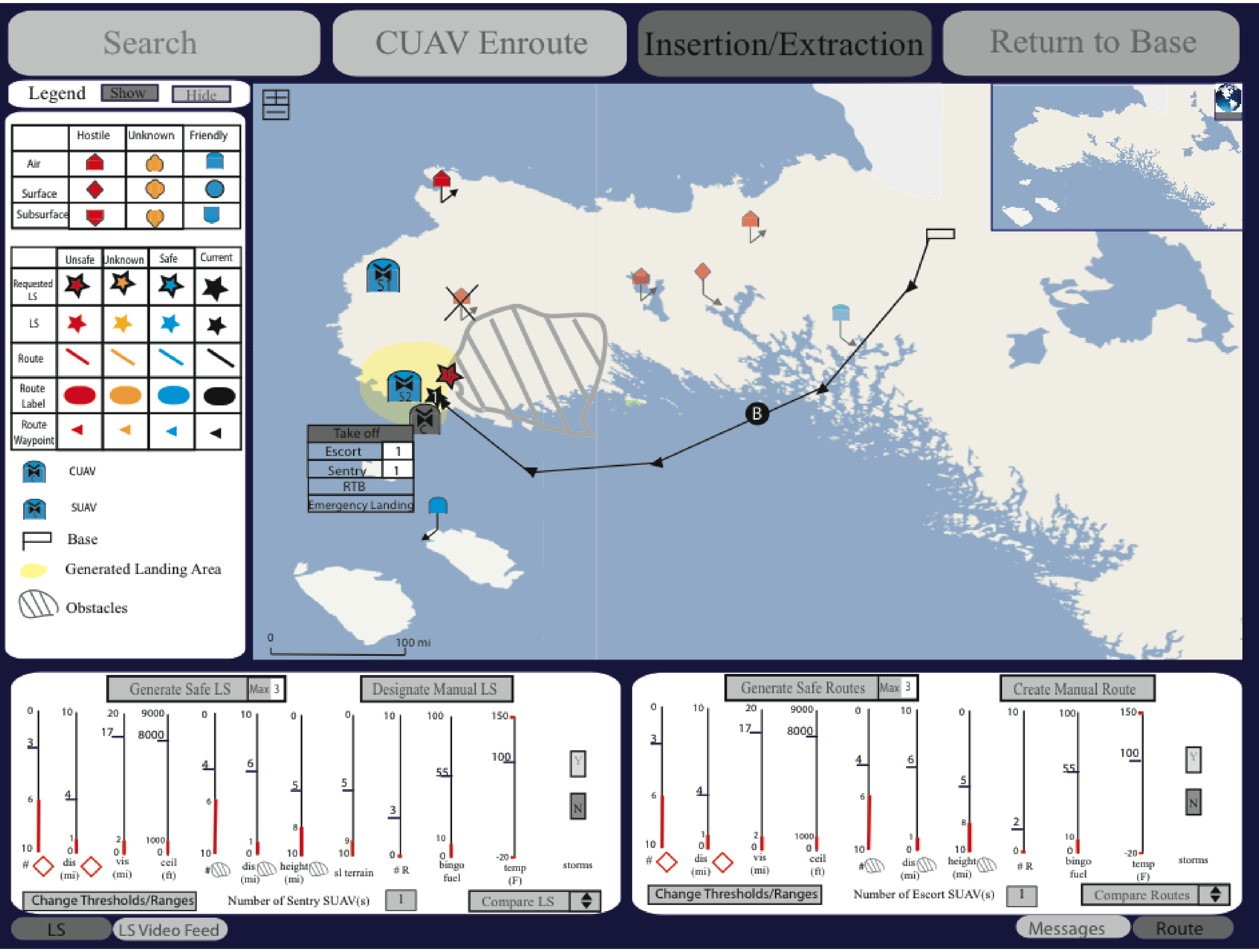
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Hostile neutralized
S1
S2
C
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi) vis (mi) ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
# dis (mi) vis (mi) ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
Generate Safe Routes
Max 3
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

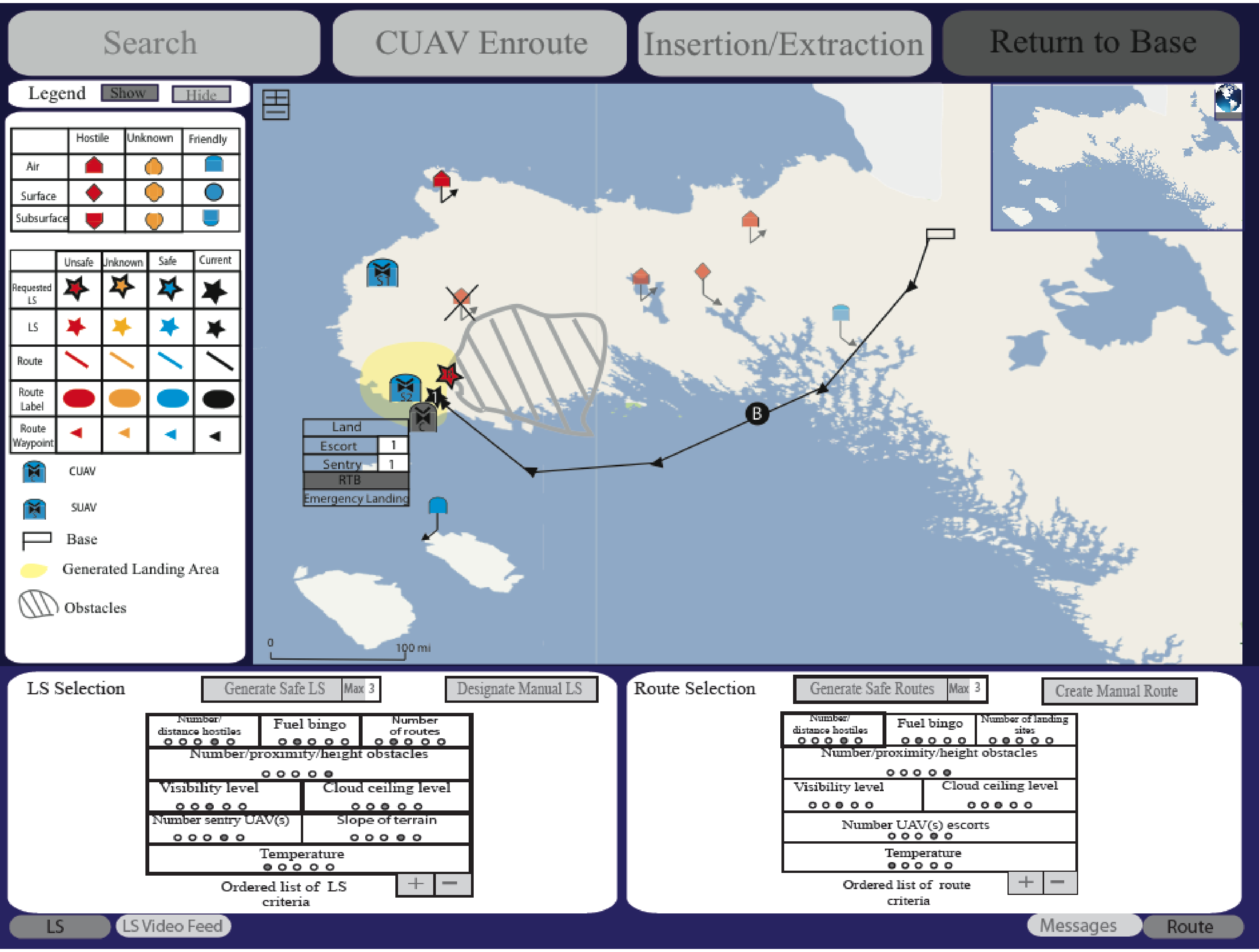


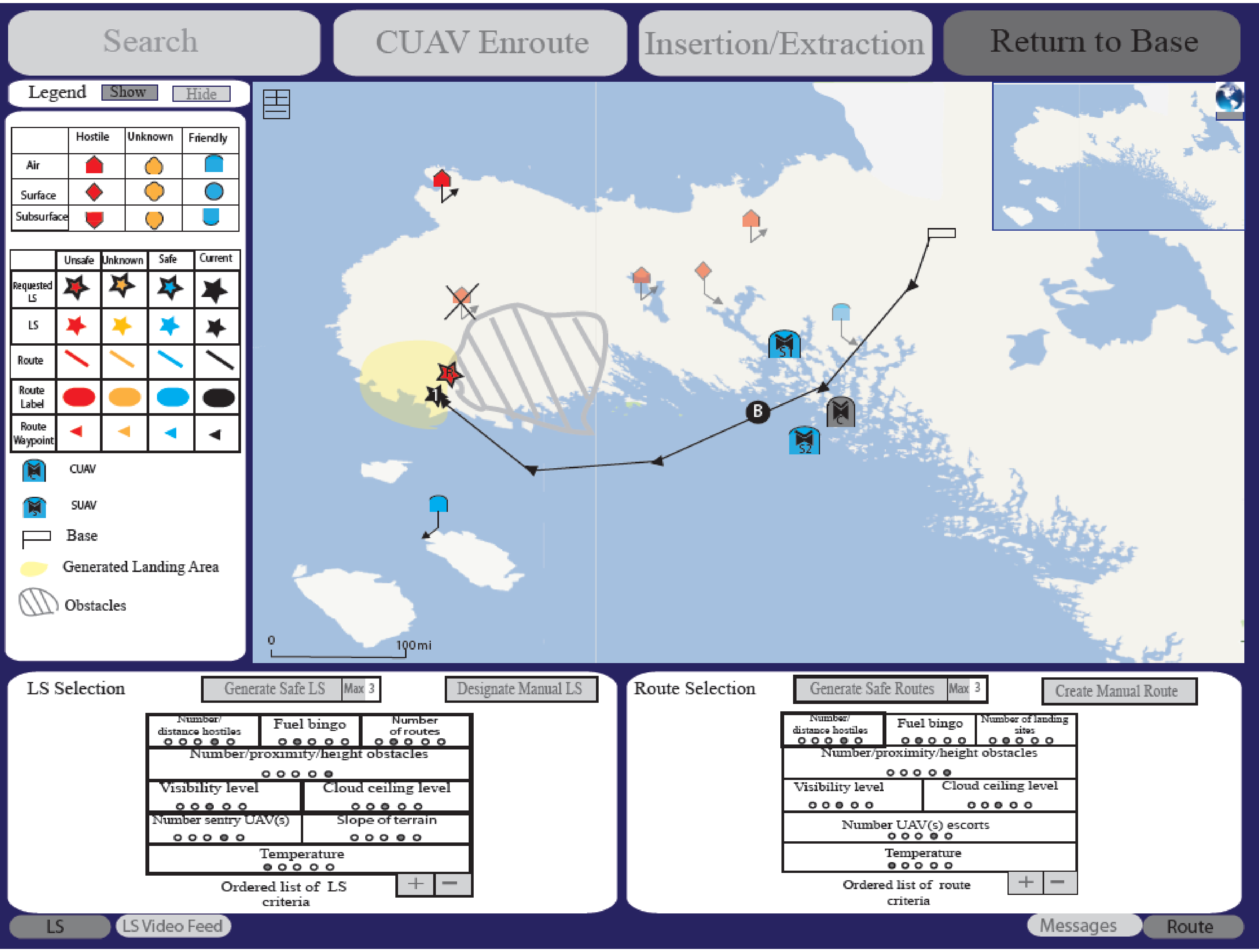
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
B
Land
Escort 1
Sentry 1
RTB
Emergency Landing
0
100 mi
Generate Safe Routes
Max 3
Create Manual Route
dis (mi)
vis (mi)
ceil (ft)
height (mi)
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Escort SUAV(s) 1
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Loading Complete
B
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
#
dis (mi)
vis (mi)
ceil (ft)
height (mi)
sl terrain
# R
bingo fuel
temp (F)
storms
Y
N
Change Thresholds/Ranges
Number of Sentry SUAV(s)
1
Compare LS
Generate Safe Routes
Create Manual Route
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route

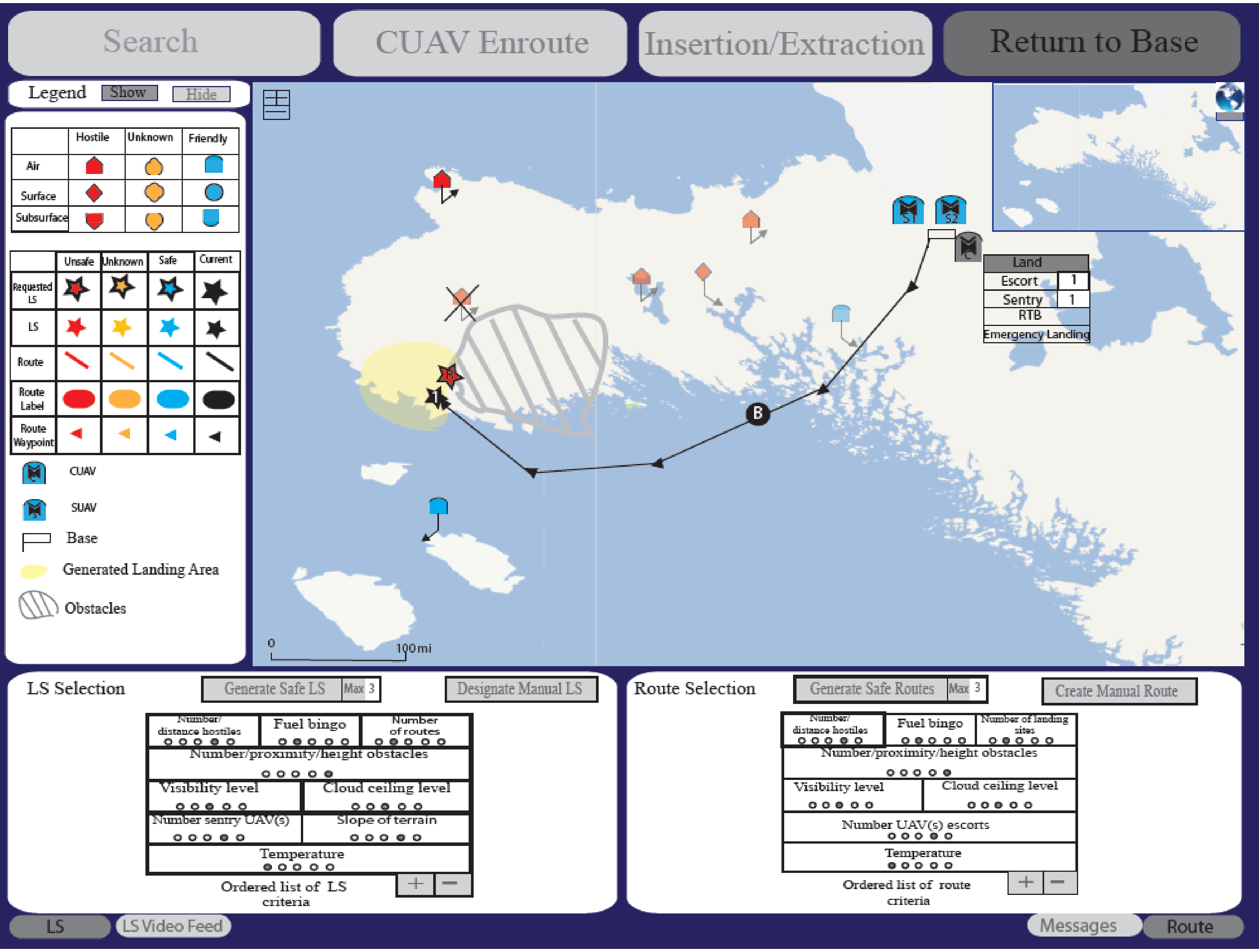


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Take off
Escort
Sentry
RTB
Emergency Landing
0
100 mi
Generate Safe LS
Max 3
Designate Manual LS
Change Thresholds/Ranges
Number of Sentry SUAV(s)
Compare LS
storms
Generate Safe Routes
Max 3
Create Manual Route
Change Thresholds/Ranges
Number of Escort SUAV(s)
Compare Routes
LS
LS Video Feed
Messages
Route


Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
S1
S2
C
B
Land
Escort
1
Sentry
1
RTB
Emergency Landing
0
100 mi
LS Selection
Generate Safe LS
Max
3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max
3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

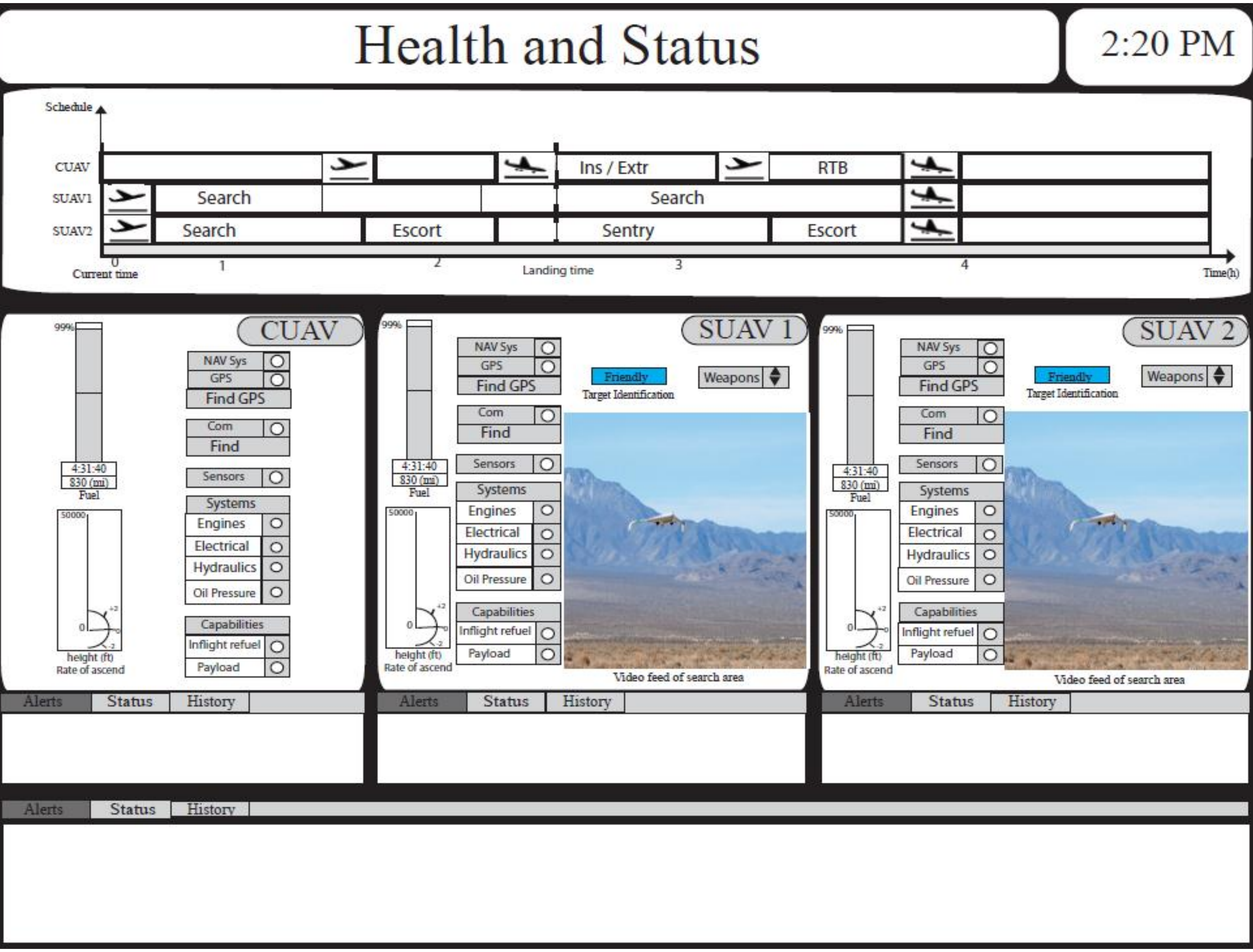


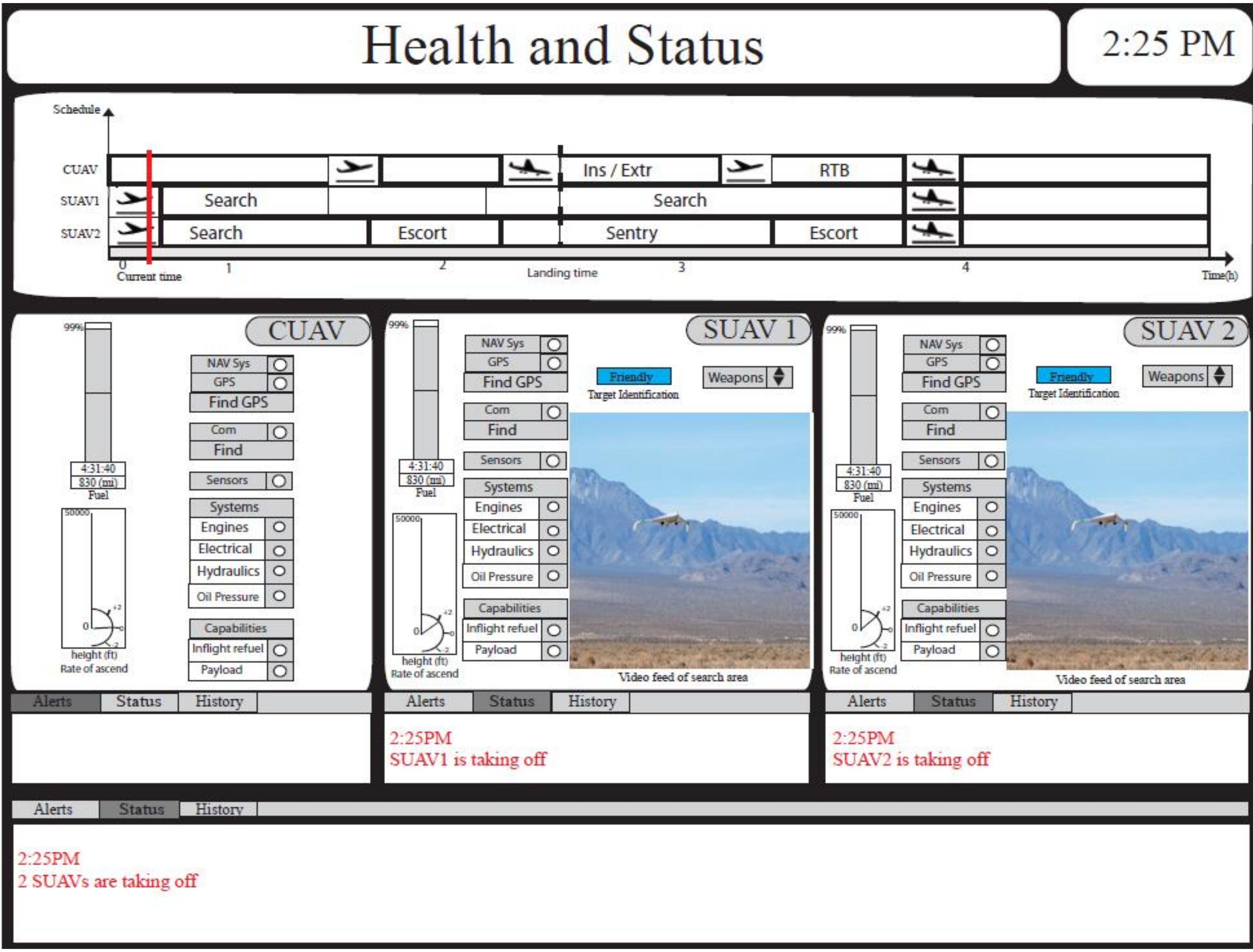
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
0
100mi
LS Selection
Generate Safe LS
Max 3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route



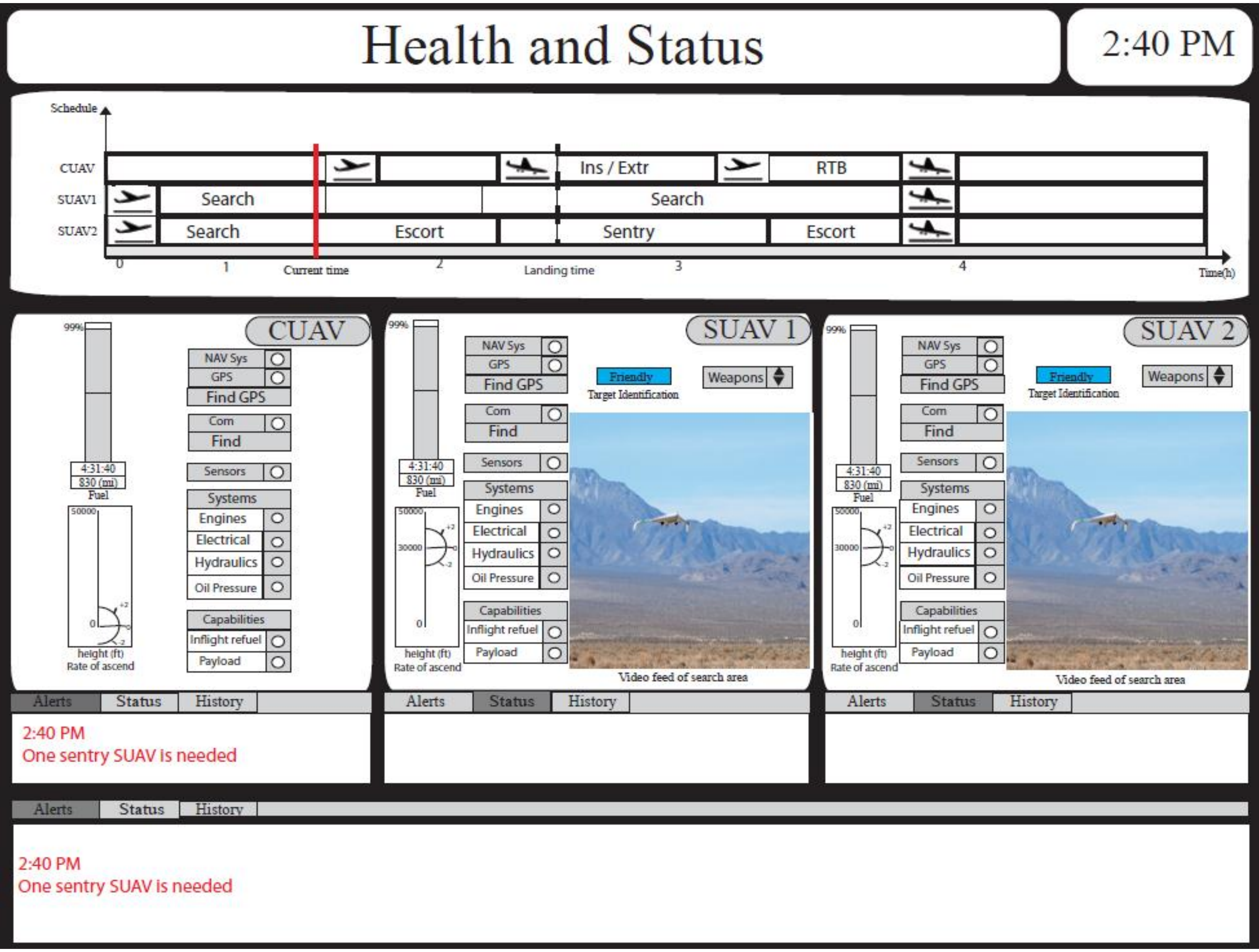
Search
CUAV Enroute
Insertion/Extraction
Return to Base
Legend
Show
Hide
Hostile
Unknown
Friendly
Air
Surface
Subsurface
Unsafe
Unknown
Safe
Current
Requested LS
LS
Route
Route Label
Route Waypoint
CUAV
SUAV
Base
Generated Landing Area
Obstacles
Land
Escort 1
Sentry 1
RTB
Emergency Landing
0
100mi
LS Selection
Generate Safe LS
Max 3
Designate Manual LS
Number/ distance hostiles
Fuel bingo
Number of routes
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number sentry UAV(s)
Slope of terrain
Temperature
Ordered list of LS criteria
Route Selection
Generate Safe Routes
Max 3
Create Manual Route
Number/ distance hostiles
Fuel bingo
Number of landing sites
Number/proximity/height obstacles
Visibility level
Cloud ceiling level
Number UAV(s) escorts
Temperature
Ordered list of route criteria
LS
LS Video Feed
Messages
Route

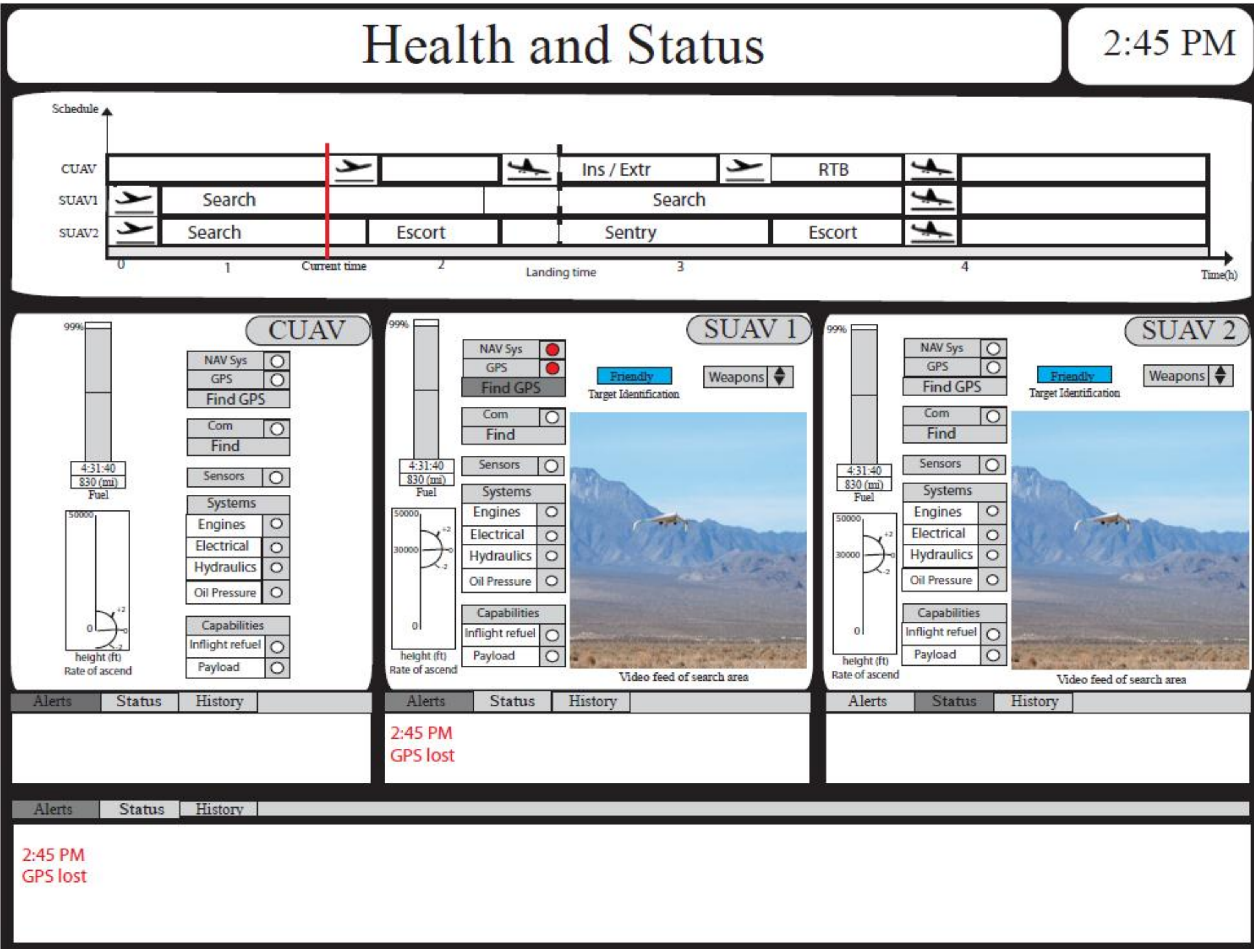
# Health and Status Display Storyboard


Health and Status
2:20 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
Current time
1
2
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Alerts
Status
History
SUAV 1
Friendly
Target Identification
Weapons
Video feed of search area
SUAV 2
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History

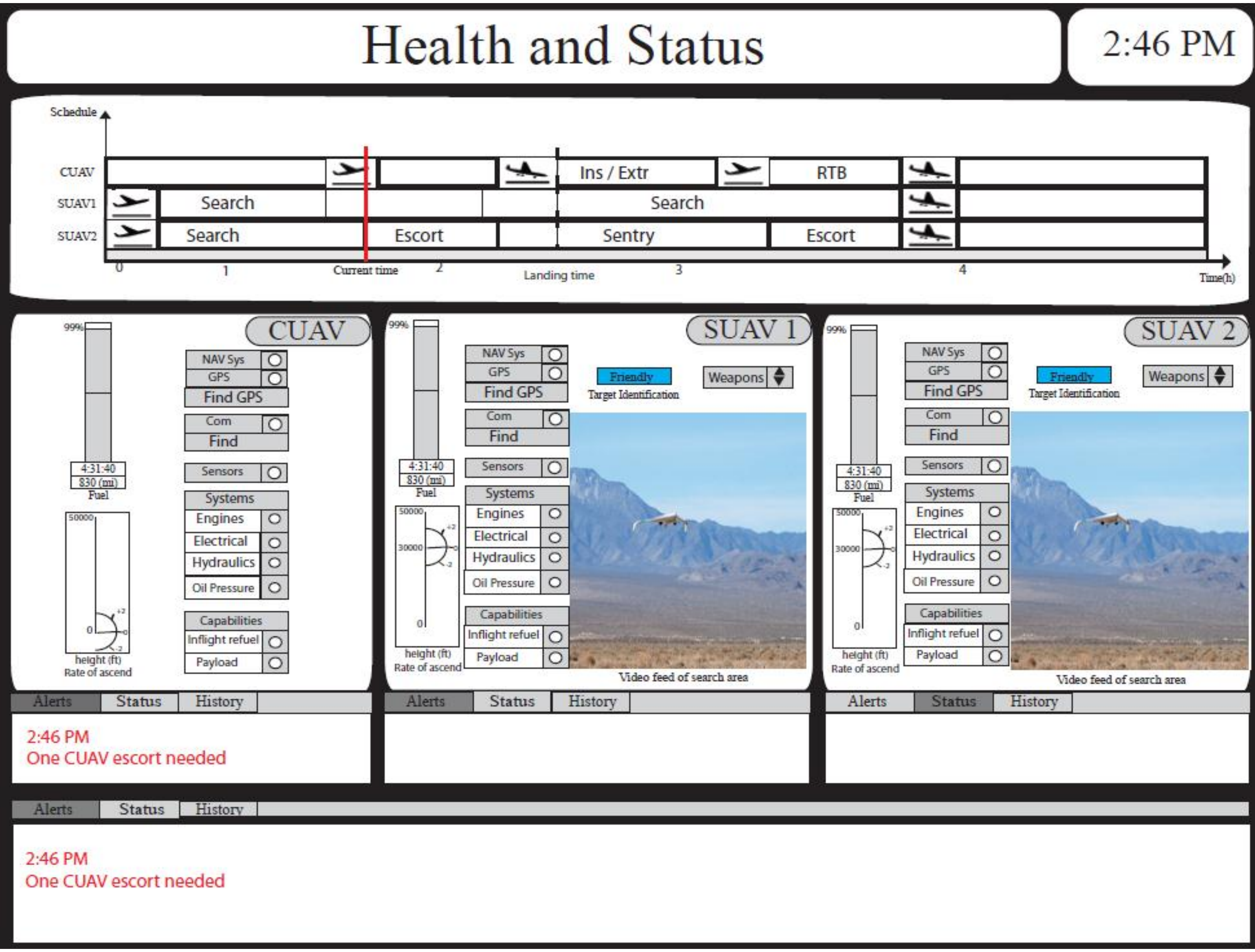


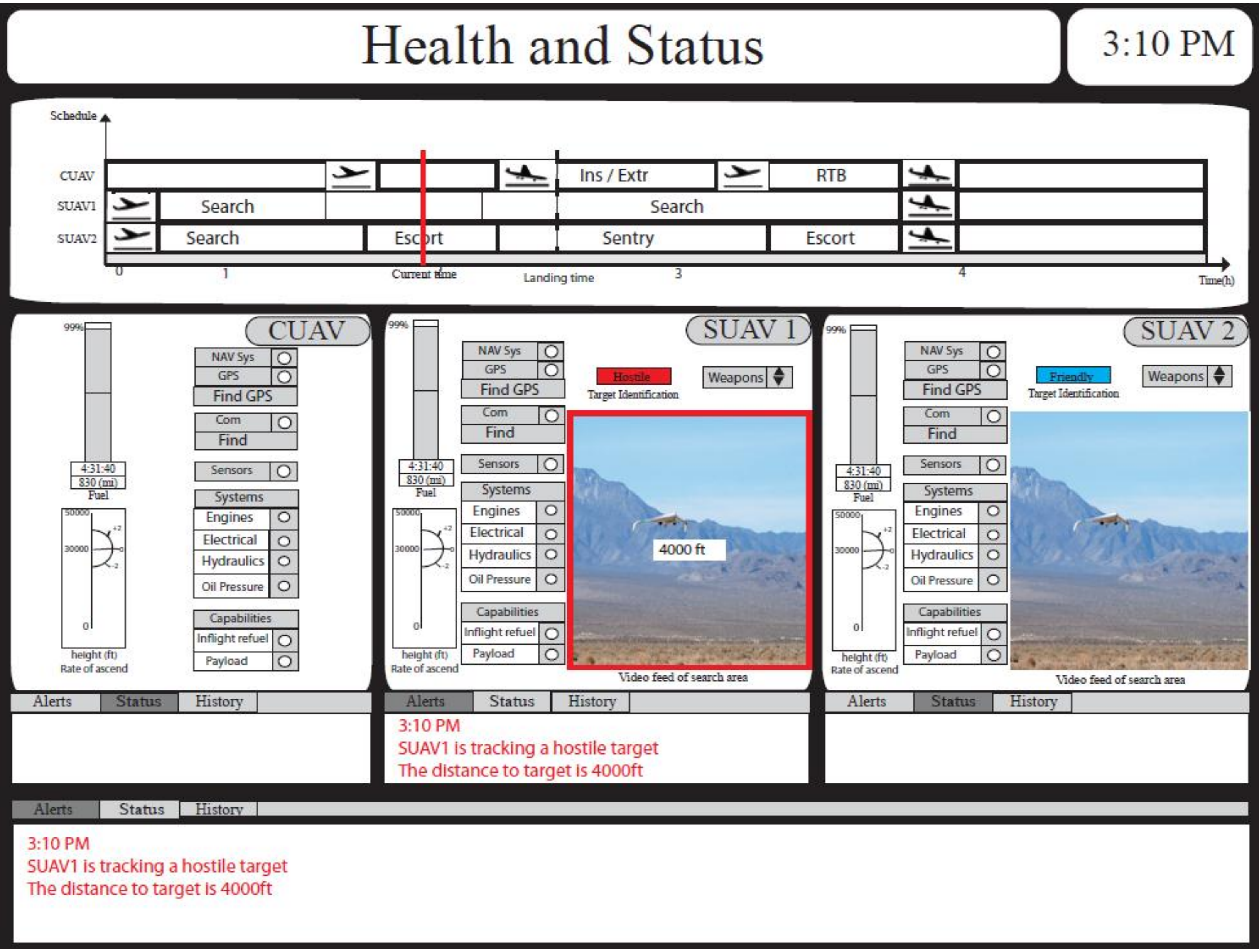
Health and Status
2:25 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
2
3
4
Current time
Landing time
Time(h)
CUAV
SUAV 1
SUAV 2
99%
4:31:40
830 (mi)
Fuel
50000
0
+2
-2
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
2:25PM
SUAV1 is taking off
2:25PM
SUAV2 is taking off
2:25PM
2 SUAVs are taking off

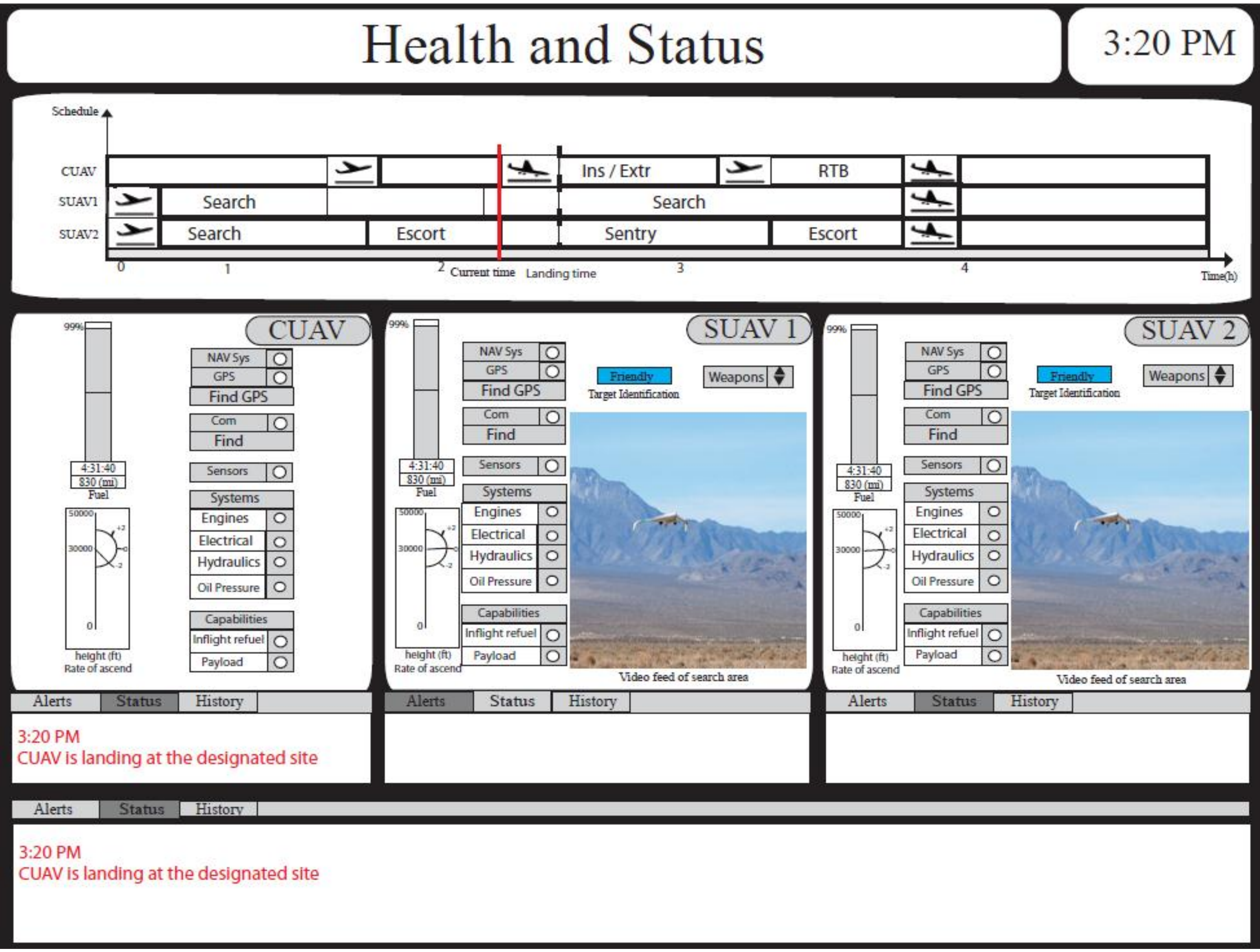

Health and Status
2:40 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
Current time
2
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
SUAV 1
Friendly
Target Identification
Weapons
30000
Video feed of search area
SUAV 2
Alerts
Status
History
2:40 PM
One sentry SUAV is needed
Alerts
Status
History
2:40 PM
One sentry SUAV is needed

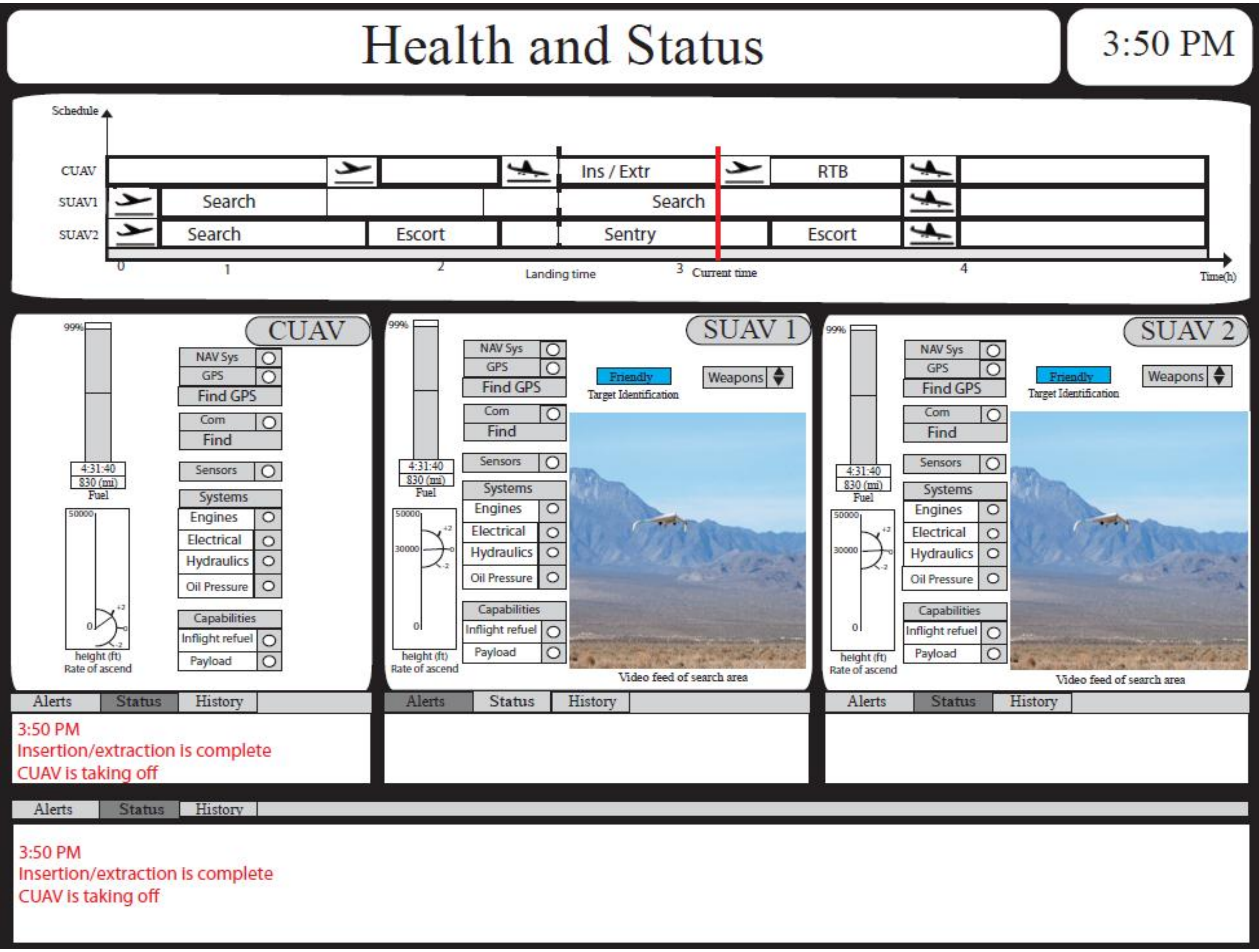


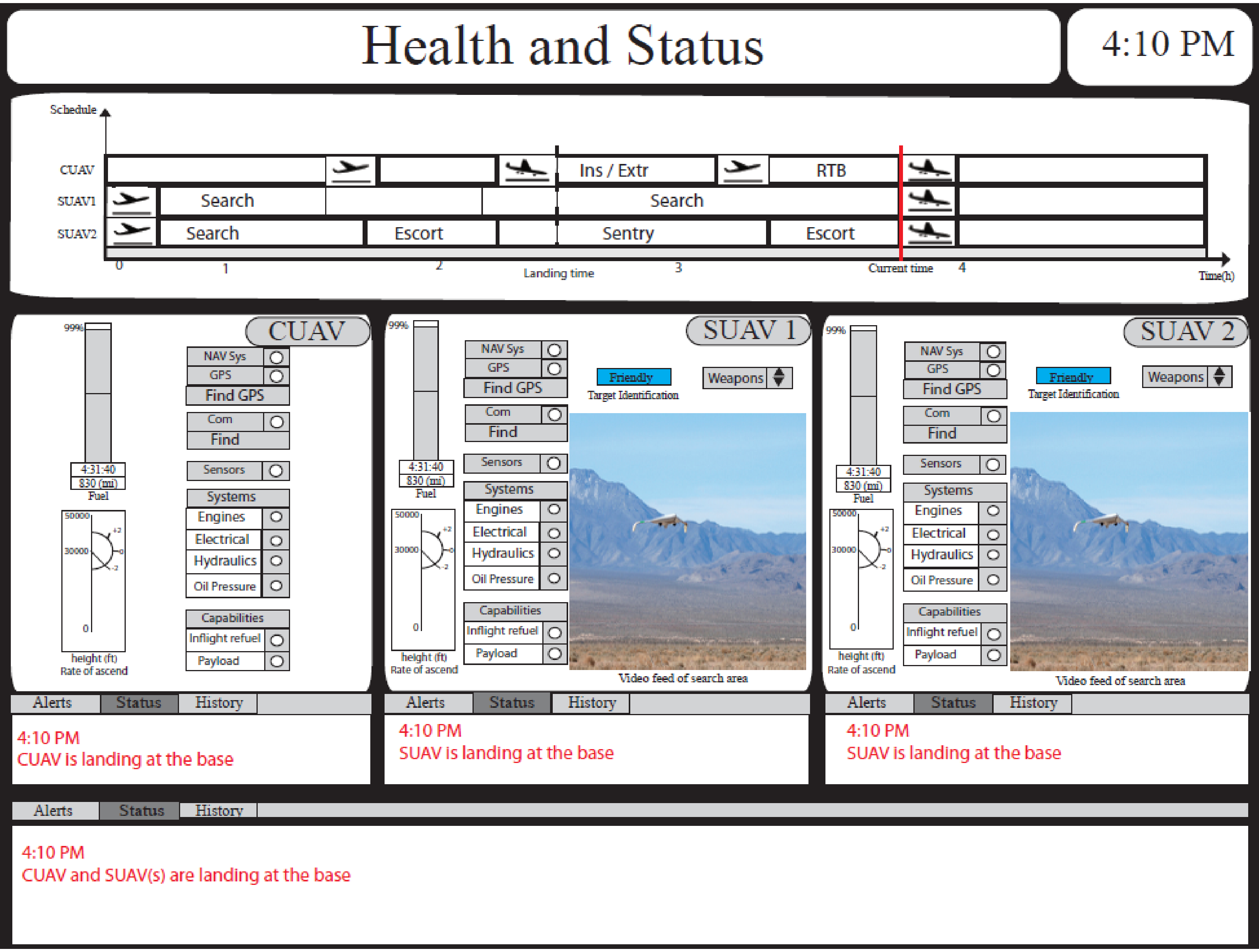
Health and Status
2:45 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
Current time
2
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
SUAV 1
99%
4:31:40
830 (mi)
Fuel
50000
30000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Friendly
Target Identification
Weapons
Video feed of search area
SUAV 2
99%
4:31:40
830 (mi)
Fuel
50000
30000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
Alerts
Status
History
2:45 PM
GPS lost
Alerts
Status
History
Alerts
Status
History
2:45 PM
GPS lost

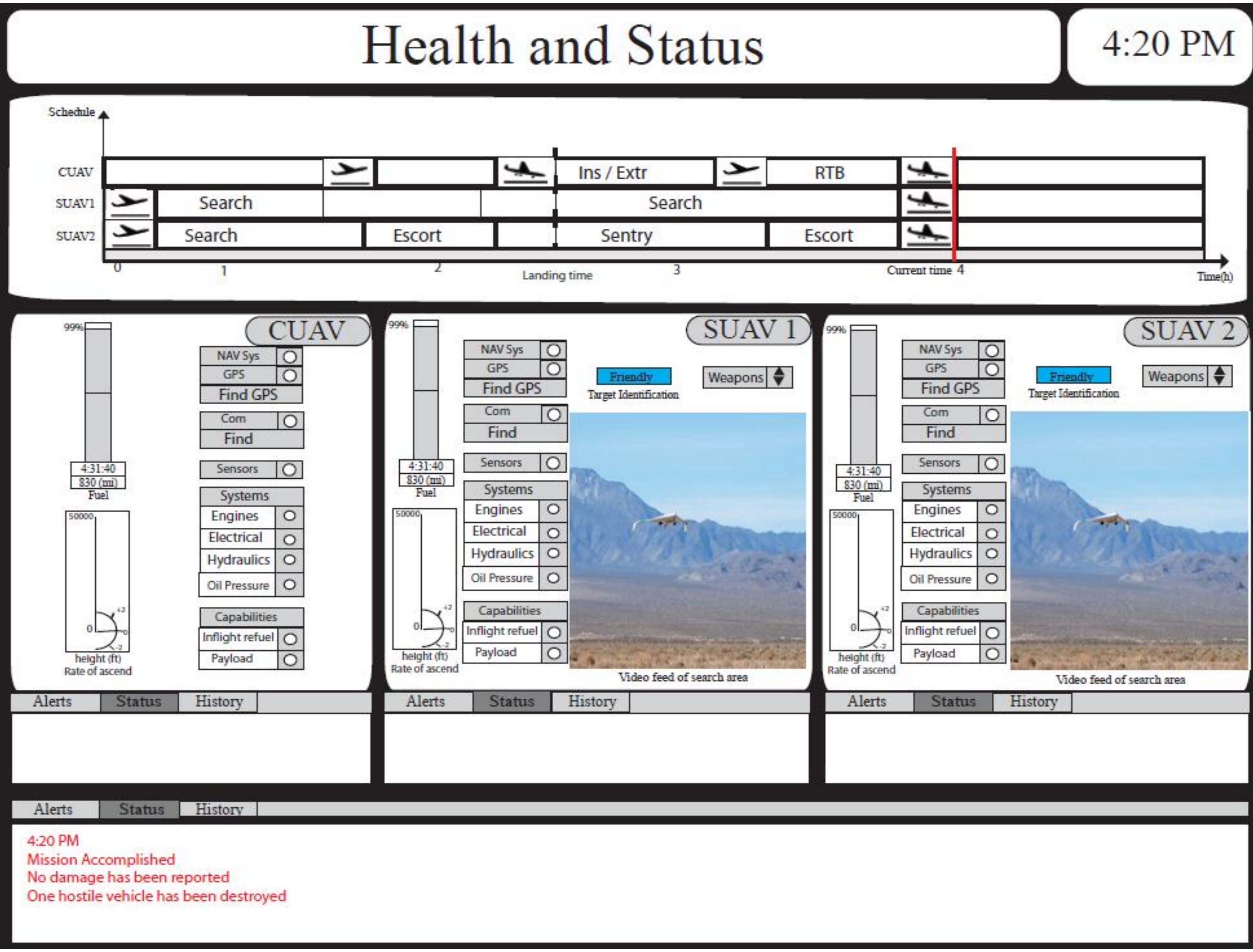

Health and Status
2:46 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
Current time
2
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
SUAV 1
Friendly
Target Identification
Weapons
Video feed of search area
SUAV 2
Alerts
Status
History
2:46 PM
One CUAV escort needed


Health and Status
3:10 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
Current time
Landing time
3
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
30000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Alerts
Status
History
SUAV 1
Hostile
Target Identification
Weapons
4000 ft
Video feed of search area
3:10 PM
SUAV1 is tracking a hostile target
The distance to target is 4000ft
SUAV 2
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
3:10 PM
SUAV1 is tracking a hostile target
The distance to target is 4000ft


Health and Status
3:20 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
2
Current time
Landing time
3
4
Time(h)
CUAV
SUAV 1
SUAV 2
99%
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
4:31:40
830 (mi)
Fuel
50000
30000
0
+2
0
-2
height (ft)
Rate of ascend
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
3:20 PM
CUAV is landing at the designated site
Alerts
Status
History
3:20 PM
CUAV is landing at the designated site


Health and Status
3:50 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
2
Landing time
3
Current time
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
0
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
SUAV 1
Friendly
Target Identification
Weapons
30000
Video feed of search area
SUAV 2
Alerts
Status
History
3:50 PM
Insertion/extraction is complete
CUAV is taking off


Health and Status
4:10 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
2
Landing time
3
Current time
4
Time(h)
CUAV
99%
4:31:40
830 (mi)
Fuel
50000
30000
0
+2
0
-2
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
SUAV 1
Friendly
Target Identification
Weapons
Video feed of search area
SUAV 2
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
4:10 PM
CUAV is landing at the base
Alerts
Status
History
4:10 PM
SUAV is landing at the base
Alerts
Status
History
4:10 PM
SUAV is landing at the base
Alerts
Status
History
4:10 PM
CUAV and SUAV(s) are landing at the base


Health and Status
4:20 PM
Schedule
CUAV
SUAV1
SUAV2
Ins / Extr
RTB
Search
Search
Search
Escort
Sentry
Escort
0
1
2
Landing time
3
Current time 4
Time(h)
CUAV
SUAV 1
SUAV 2
99%
4:31:40
830 (mi)
Fuel
50000
height (ft)
Rate of ascend
NAV Sys
GPS
Find GPS
Com
Find
Sensors
Systems
Engines
Electrical
Hydraulics
Oil Pressure
Capabilities
Inflight refuel
Payload
Friendly
Target Identification
Weapons
Video feed of search area
Alerts
Status
History
4:20 PM
Mission Accomplished
No damage has been reported
One hostile vehicle has been destroyed

Questions?

# Cognitive Walkthrough

"Quick and dirty" usability testing

"The Cognitive Walkthrough has proven to be a robust method that gives good results if not taken too seriously." Clayton Lewis

1) The user sets a (sub)goal to be accomplished with the system.
2) The user searches the interface for currently available actions (menu items, buttons, command-line inputs, etc.).
3) The user selects the action that seems likely to make progress toward the goal.
4) The user performs the selected action and evaluates the system's feedback for evidence that progress is being made toward the current goal.

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