Design Methodology for Unmannded Aerial Vehicle (UAV) Team Coordination

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Executive Summary

Unmanned Aerial Vehicle (UAV) systems, despite having no onboard human pilots, currently require extensive human involvement to accomplish successful mission operations. Further, successful operations also require extensive colalboration between mission stakeholders, including operators, mission commanders, and information consumers (e.g. ground troops relying on intelligence reports in their area).

Existing UAV system interfaces provide little to no support for collaboration between remote operators or for operators to collaborate with information consumers. As reliance on UAVs continues to increase in military and civilian operations, this lack of support for collaboration will likely become a substantial limitation of existing UAV systems.

In order to introduce effective collaboration support to UAV system interfaces, it is essential to understand, and be able to derive system design requirements that address, the necessary group interactions that occur in UAV task enviroments. However, few collaborative requirements analysis methods exist, and to our knowledge, no method exists that captures design requirements for collaborative decision making in complex, time-critical environments.

This report describes the development of a new design requirements analysis method for deriving information and functional requirements that address the collaboration needs of UAV (and other complex task) operators, and the needs of stakeholders interacting with these operators. More specifically, theis method extends a recently developed requirements analysis method, called the Hybrid Cognitive Task Analysis (CTA) method, which enables the generation of information and functional requirements for futuristic UAV system interfaces. The original Hybrid CTA method focused on deriving single user system interface requirements. This work extends this method by introducing analytic steps to identify task and decision-making dependencies between different UAV operations collaborators.

This collaborative extension to the Hybrid CTA utilizes the notion of *boundary objects*, an analytic construct commonly used in the study of group work. Boundary objects are physical or information artifacts that cross the task boundaries between members of distinct groups. Identifying boundary objects in complex task operations help the analyst to identify task and decision-making dependencies between local and remote collaborators. Understanding these dependencies helps to identify information sharing requirements that the UAV system should support.

This report describes the analytic steps of the collaborative extension, and provides background information on the original Hybrid CTA method and the boundary object construct. The report also describes a project in which the new design requirements method was used to revise a proposed set of UAV operator displays.

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Chapter 1 Introduction

Unmanned Aerial Vehicle (UAV) systems, despite having no onboard human pilots, require a high amount of human involvement to accomplish successful operations. A typical modern UAV system involves a launch crew (1-3 people), a mission crew (2-5) people, personnel using the imagery data captured from the UAV onboard sensors, such as forward ground troops or intelligence analysts, and possibly others, including lawyers and politicians. Furthermore, since a single UAV mission can last for over 24 hours, missions often involve one or more shift changes of the mission crew.

Thus, there is a significant amount of human-human and human-vehicle interaction involved in UAV system operations. Much of this collaboration is done between geographically distributed people (e.g. the mission crew may be in the United States while the launch crew and information consumers may be in Afghanistan).

Since the UAV system interface is the primary communication link between the UAV and its human operators a poorly designed interface could have dire consequences, including human casualties. The design of the UAV system interface also impacts the collaborative efforts discussed above. For example, handing off the control from the UAV launch crew in Afghanistan to the mission crew back in the United States involves both sets of operators to tightly coordinate their interactions with the UAV system interface on their respective control stations to achieve the UAV handoff operation. If one set of operators is currently involved in a shift change, is distracted, or has computer problems there may be a breakdown in coordination, resulting in an unsuccessful handoff.

During current UAV handoff operations, it is often not clear which operator is in control of the UAV. Existing UAV system interfaces provide little to no support for collaboration between remote operators or for operators to collaborate with information consumers. As the reliance on UAV increases in military and civilian operations, this lack of support for collaboration is expected to become a substantial limitation of UAV systems.

Besides, with the advances in technology, futuristic UAVs are expected to become increasingly autonomous and, thus, the organization of the UAVs' control teams might be altered. As presented in Figure 1.1, in current UAV missions, it is usual to have multiple operators responsible for a single UAV, however, futuristic UAV missions are expected to have single operators controlling multiple UAVs. In this manner, it is also expected that the complexity of the interfaces grows, requiring that designers develop increasingly refined and robust methods to generate interface requirements.

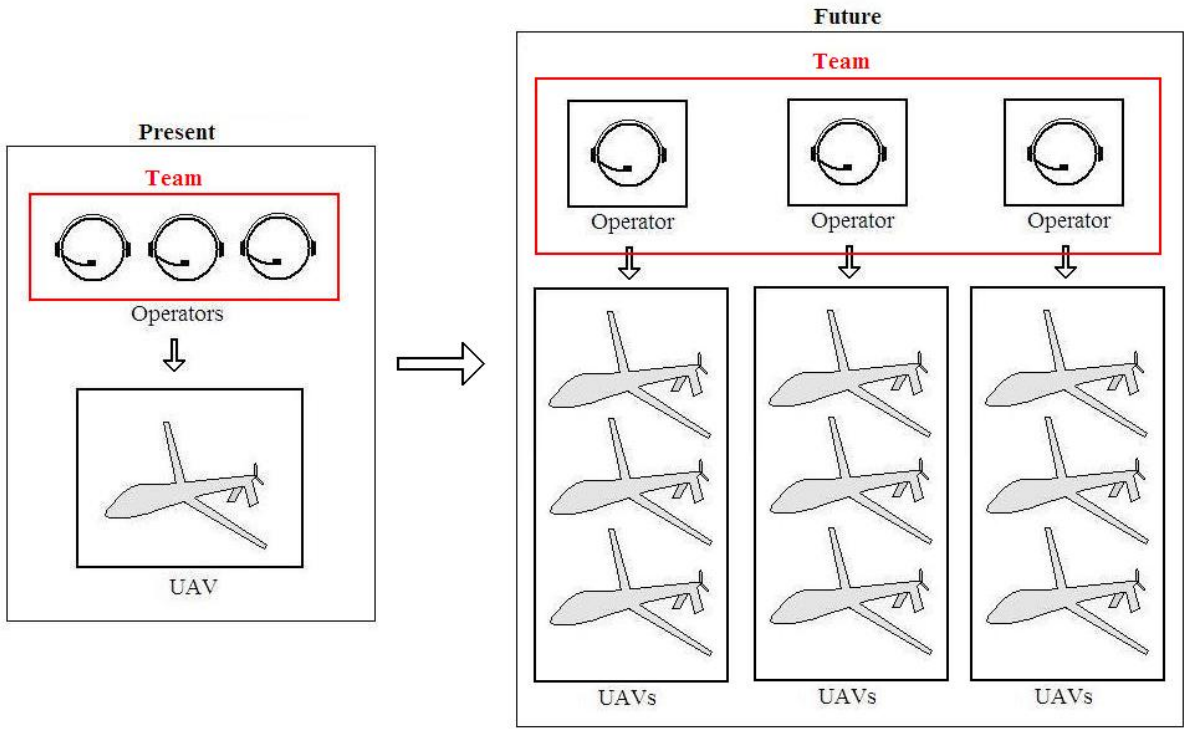


Figure 1.1 - Current and Futuristic UAV control teams

A common method currently used by designers to generate functional and display requirements in the development of human-computer interfaces to control UAV systems is the Cognitive Task Analysis (CTA), which relies on the modeling of the mental activities of the task operator (May & Barnard, 2003).

A recent CTA method, called the Hybrid CTA, has been developed to generate system design requirements for futuristic UAV control schemes such as the one presented in Figure 1.1. However, the Hybrid CTA and other design methodologies derive system requirements that support single users engaged in individual tasking and decision making, being insufficient to derive collaboration requirements. This becomes an issue when it is necessary to develop interfaces for complex systems, such as UAV systems, where human-human interaction is significantly involved and teamwork can not be neglected compared to task work in order to obtain acceptable performance.

This research aims to extend the Hybrid CTA design methodology. The reason for this proposed extension is that this CTA method limits the potential for overall UAV systems operations by focusing on the needs of the individual team members, often ignoring the collective decision making and coordination that is actually required throughout UAV mission operations. In order to address these limitations for teamwork design, a new design methodology will be presented to derive information and functional requirements aimed at supporting collaboration, communication and coordination within UAV system operators.

The remainder of this chapter discusses the scope and the research context of this work, states the problem to be addressed, and the goals of this research.

1.1 Background and Research Context

This research falls under the general research field of Aeronautics and Astronautics (Aero-Astro). This research field is concerned with studying the conception, design, implementation, and operation of aerospace products and systems. According to Massachusetts Institute of Technology (MIT) Aero-Astro department description this field focuses on creating:

> "technologies critical to aerospace vehicle and information engineering, and develop the architecture and engineering of complex high-performance systems."
> (Reference: MIT website – *http://www.mit.edu*)

Since the final goal of this research is to develop a method to design human-computer interfaces for controling systems, this research relates specifically to the systems engineering aspects of Aero-Astro. In particular, this research explores systems that are only partially automated, which means that human performance is strongly relevant to the appropriate system functionality. Therefore, there must be a high concern with factors that may affect people involved with the system. Thus, the perspectives that will be used in this research are human factors related. The method proposed in this work will be based on the understanding and modeling of the task and the cognitive activity of the system operators. This work contributes to the research area concerned with system requirements analysis and specifications through CTA methodologies.

The design of interfaces for complex systems typically focuses on the tasks that individual users must accomplish during any kind of mission or operation. A common approach used for designing complex systems is the CTA. It is a powerful tool for improving existing technologies, but it is insufficient for futuristic environments, since it requires access to subject matter experts and existing system implementations (Redding, 1989).
For this reason, Nehme et al. (2006) proposed the Hybrid CTA, an extension of the CTA method which addresses the lack of subject matter experts and previous documentation or implementation, issues inherent to futuristic unmanned vehicle systems. The Hybrid CTA enables requirements generation from a representative scenario of a futuristic task domain and compensates for the lack of task experts by using decision ladders to replicate the thought processes of a potential operator. However, the existing Hybrid CTA method does not specifically generate requirements related to collaboration or teamwork in general.

Since this work focuses on designing for futuristic environments (specifically, to design interfaces for future UAV systems), the Hybrid CTA was the basis for this work. However, since the Hybrid CTA approach is also insufficient for the purposes of teamwork support, this work will focus on a new approach which will be an extension of the Hybrid CTA with interest in the comprehension of the important aspects of team collaboration that would be missed by the Hybrid CTA approach.

It is intended that the proposed approach will build on, and not replace the information and functional requirements derived from the Hybrid CTA and will associate these requirements with the ones derived from the collaborative work study. Thus it is expected that the expanded approach will result in a more complete and detailed design. Also, since teamwork is an essential component in the operation and control of the systems considered in this research, this extended approach will help reduce human error or misinterpretation. Therefore, it should improve task performance and reduce the chances of system breakdown.

Nevertheless, it is known that possible issues inherent to a new, and, therefore, never tested method, may exist. First, it is possible that the data generated by the new method may be too complex to really map the team environment. Second, the method may generate information and functional requirements that may be too refined, with such a high volume of information that may result in interfaces that will overload and confuse the operators. Third, it may be hard to understand and represent the dependencies between team members and this can result in mistaken requirements generation. However, a full evaluation of the method is beyond the scope of the project and is left for future work.

1.2 Problem Statement and Research Hypothesis

The problem addressed by this research is that existing methods for deriving information and functional requirements for human-computer interfaces for operation and control of UAV systems do not support collaboration between team members.

The central research hypothesis of this work is that examining specific roles of team members in a collaborative task will help to identify information and functional requirements related to teamwork aspects (e.g. communication, collaboration and coordination) in the operation and control of complex systems. It is important to highlight that the Hybrid CTA method will not be abandoned, instead, it will be associated with the collaboration study.

1.3 Research Goals

This research has two main goals:

Goal 1. To develop a method to take into account teamwork in the requirements derivation for interface design for complex systems operation and control.

In order to achieve this goal, I first conducted a literature review to understand the existing methods and how they were used to derive requirements, and also to acquire tools (e.g. decision ladders, boundary objects, cognitive task analysis) to be used in the development of the new method.

Then, I studied in detail, from the point of view of decision making processes, a representative complex team task, in particular involving UAV operations.

Then, based on the knowledge acquired by the literature review, and by the proposed case study, a new method was developed for interface requirements generation.

Goal 2. To apply the developed method to the design of UAV system displays.

Based on the method developed in the Goal 1, I re-designed a proposed set of UAV operator displays developed as part of an experimental platform used to investigate decision and collaboration support technologies for UAV team operations. The re-designed displays were analyzed to verify if they satisfied the requirements generated in goal 1.

1.4 Results and Contributions

The main contribution given by this work is the developed method (Hybrid CTA Collaborative Extension). The method may be used to design complex systems in a wide variety of applications involving teamwork.

1.5 Organizational Overview

The organization of the remaining chapters reflects the process of creating the new requirements method, from its theoretical background to its development and application.

Chapter 2, *Background*, sets the foundations of this work by presenting a brief overview of the existing methods of deriving requirements for interface design. It also describes the background used in the development of the method.

Chapter 3, *The Hybrid CTA Collaborative Extension*, presents a description of the method and details each step of the proposed approach.

Chapter 4, *Application of the Method to a Representative UAV Team Task*, exhibits the application of the method to a representative collaborative UAV task. The process of collaboration in this environment is detailed and the outcome of the chapter is a set of design requirements for UAV team displays.

Chapter 5, *Re-Designing Displays Based on the Hybrid CTA Collaborative Extension*, describes the re-design of a set of existing UAV system displays based on the requirements set obtained in Chapter 4 and also to make comparisons with displays designed without the new method (based exclusively on the Hybrid CTA approach).

Chapter 6, *Conclusion*, concludes this report by indicating how the research goals have been addressed. It also presents the contributions and possible future research that can be developed from this work.

Chapter 2 Background

This report describes the development of a new method to generate collaborative interface requirements for operators of complex systems. This chapter presents the most relevant tools and concepts that will be required for a complete understanding of this research.

First, the methods on which this work was built are presented: the CTA (Cognitive Task Analysis) and the Hybrid CTA (an extension of the CTA for futuristic systems). Next, the specifics tools that were utilized in developing the new method are described, including decision ladders and boundary objects.

2.1 Cognitive Task Analysis (CTA)

According to May & Barnard (2003) CTA techniques were developed to model the mental activity of a task operator. These techniques are related to methods for understanding the cues, patterns and relationships people perceive, the knowledge they use and the strategies they apply (Klein et al., 1997) and they identify the aspects of the system that place heaviest cognitive demands on the user (including memory, attention and decision making) (Barnard & May, 2002).

A CTA allows us to understand how to design interfaces that will provide the operator with all the necessary information for adequate system controllability, however, avoiding cognitive overload. It clarifies the aspects of a given task that can be better executed relying exclusively on human input and aspects for which computer support can be helpful or indispensable.

In other words, applying a CTA method, the analyst is concerned with system observation from the viewpoint of the operator who will perform a specific task and with obtainment of information that will allow the designer to focus upon minimizing system features that the user will find hard to learn and, thus, likely to lead to mistakes. By identifying and highlighting where potential challenges could occur, designers can create a system that leaves more time for the user to perform the given task rather than struggle with using the interface (Barnard & May, 2002).

Redding (1989) indicated the essential components of a CTA in terms of understanding the knowledge structures and the mental processes involved:

- assessing individual abilities;
- assessing changes in knowledge base;
- identifying task components;
- identifying differences between novice and experts;
- identifying the conceptual and procedural knowledge of similar components;
- specifying the conditions which best facilitate progression from one knowledge state to another.

There are many different methods for conducting a CTA. Klein (1993) identified four broad classes of CTA, including questionnaires and interviews, controlled observation, critical incidents, and analytical methods. Although there may be common aspects among CTA methodologies, they all vary with respect to how they elicit expert knowledge, represent expert knowledge, and use the tasks in question to bring about expert performance. However, regardless of the method used; CTA should include the following steps (Brenner et al, 1998):

- mapping out the task using task analysis;
- identifying the critical decision points;
- clustering and linking the decision points;
- prioritizing the decision points;
- diagnosing and characterizing the decisions as to the strategies used, cues signaling the decision points and the inferences made regarding the cues and decision points.

2.2 Hybrid CTA

Given the fact that the current CTA approaches rely on observing strategies and decision making of one or more task experts, it is extremely hard to apply these methodologies to futuristic systems for which there are no predecessors (Cummings & Guerlain, 2003; Scott et al., 2005). However, the CTA was amended to be used on futuristic systems by the development of the Hybrid CTA method, which takes into account the lack of subject matter experts and documentation (Nehme et al., 2006).

Since this work will focus on futuristic highly autonomous UAV systems, it will face the issue addressed by the Hybrid CTA methodology: the lack of the UAV system implementation and, thus, of expert operators of highly autonomous UAV systems.

The Hybrid CTA enables an analyst to generate information requirements and recommendations for an interface design from a high level description of a mission goal or a scenario description of a futuristic system (Nehme et al., 2006).

The Hybrid CTA method relies on a four step process that includes deconstructing the mission scenario description into a scenario task overview, describing the temporal constraints and relationships of the scenario events into an event flow diagram, generating information and functional requirements that address the situation awareness needs of task operators, and mapping the task operators' critical cognitive decision making processes. This final step enables display requirements and possible functional allocations between the operators and the automation systems to be identified (Nehme et al., 2006).

The following sections detail these four steps.

2.2.1 Scenario Task Overview

As described by Nehme et al. (2006), this is the step in which the mission and the scenario in which it takes place are explained. According to the changes that may occur in the operator tasking, the mission may be broken in sub-phases. The scenario task overview (e.g. Figure 2.1) should contain a description of each sub-phase and their associated sub-goals. It should also present the expected operator's sub-tasks in order to accomplish each sub-phase.

Any assumptions that are made during this step of the phase goals should be explicitly stated. This scenario task overview serves as the basis for the task analysis.

	Phase Goals	**Phase Breakdown**
Mission Execution	Monitor Target Phase	- Search UUV should continue to surface at scheduled checkpoints to continue monitoring target – ATR should continue to flag target as contact of interest and update imagery. - When onboard ATR no longer has target in camera range, target tracking should be handed off to UAV… last known location should be available to Sentry UUVs, to UAV's MTI program, and to LCS. - When target is lost by Search UUV(s), Sentry UUVs, UAV (if available) & LCS should be given last known location by UUV as well as historical and predicted track of target. - Monitor Target phase is complete once UAV is tracking the target, or Search UUVs handoff to Sentry UUVs. - LCS should retask or recall Search UUVs
	Tracking Target Phase	- UAV should use last known location from UUV + MTI software to track target. UAV should send LCS MTI feed. - LCS should monitor LCS MTI feed - LCS should determine estimated time of arrive of target at harbor entrance based on MTI feed from UAV and schedule Sentry UUVs to surface and capture EO-imagery of expected target location at that time via UAV communication link (this should be automated to the highest degree possible). - Tracking Target phase is complete once target reaches Sentry UUVs, UAV tracking could be discontinued at this time.
	Exit Harbor Phase	- Within a predetermined window of time, Sentry UUVs should surface and wait for target arrival, - UUV should capture and send collected EO-imagery to LCS via UAV. If UAV is unavailable, surface at scheduled time intervals to retry EO-imagery transmission. Continue cycle until Ack is received from LCS. Regardless of Ack status, at least 1 UUV will track the target out of the harbor based on a set of predetermined criteria. - LCS should determine tracking profile of Sentry UUVs and determine when they will be retasked or recalled

Figure 2.1 - Scenario Task Overview - Excerpted from Nehme et al., 2006

2.2.2 Event Flow Diagram

In this step, the temporal constraints are presented and the sub-tasks are organized in a temporal order in relation to each other. The event flow diagram is composed of three basic types of events (Nehme et al., 2006):

- Loops: events that occur repeatedly until some predetermined event occurs,
- Decisions: events that require knowledge-based input from operator and
- Processes: events that require human-computer interaction to support a subtask.

Figure 2.2 represents a model of an event flow diagram.

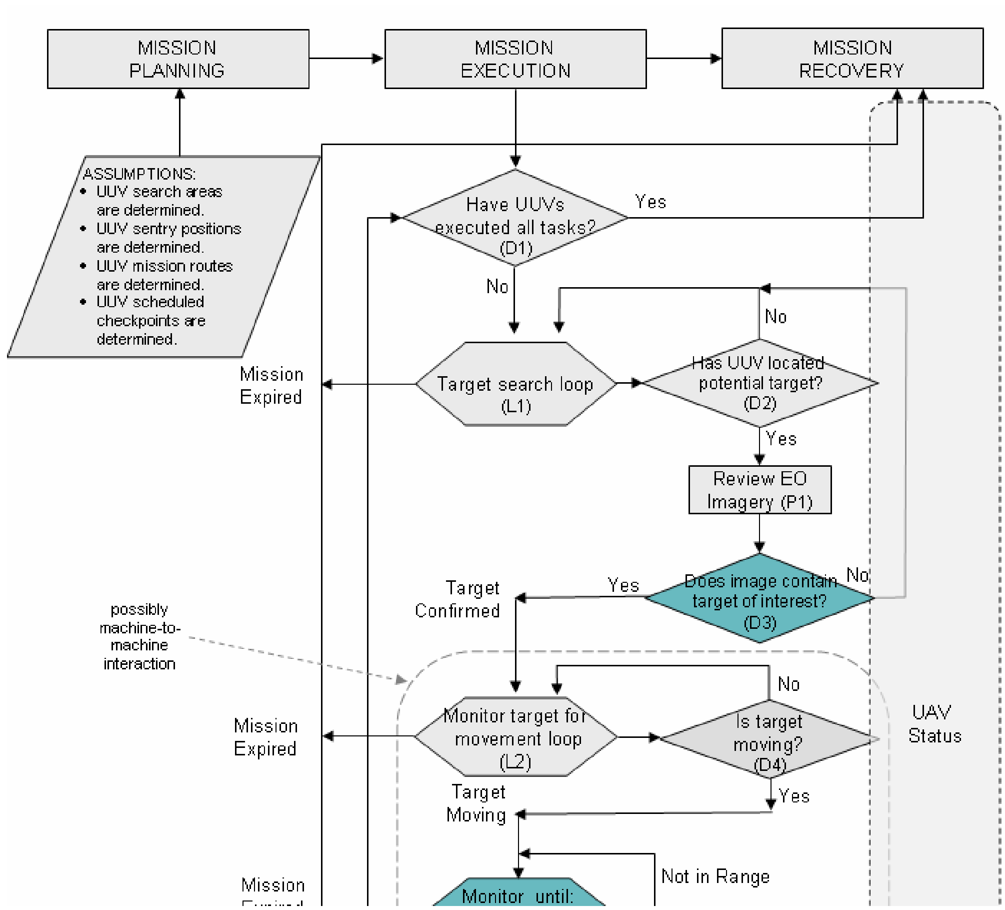


Figure 2.2 – Event Flow Diagram – Excerpted from Nehme et al., 2006

2.2.3 Situation awareness requirements

The third step consists of generating the situation awareness (SA) requirements (e.g. Figure 2.3) for each of the mission phases and associated sub-tasks identified in the first two steps (Nehme et al., 2006).

According to Endsley (1988):

> "[situation awareness is] the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."

The SA requirements generated in this step are divided into these three SA levels: Perception, Comprehension, and Projection (Endsley, 1995). For each of these levels, the situation awareness requirements associated with each mission phase and subtask (derived in step 1) are specified. The temporal constraints from step 2 are also considered in the situation awareness requirements generation (Nehme et al., 2006).

	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
Acquire Target Phase	- Visual & audible alert when UAV leaves or returns on-station duty (D2) - All agents' position information (D3) - Hazardous areas (L1, D2) - Geo-spatial boundaries (L1, D2) - Indicate communications link coverage range when on-station (D2, D3) - Sensor coverage should be visualized on tactical map (D2, D3) - Visual/audio feedback for confirmation of target acquisition (D2, L1, D3)	- Error/alert message clarification (L1, D2, P1, D3) - Vehicle limitations (on demand) (P1, D3) - UUV schedules (D2, D3) - Health & status of UUVs (L1, D2) - Strength of comms link to UUV scheduled to check in should be indicated on tactical map (based on current position of UAV and comms range) (D2, L1, D3) - Expected connection should be indicated at UUV scheduled checkpoint time – if UAV out of range / unavailable, missed connection should be indicated (L1, D2) - Temporal constraints (P1)	- Schedule of estimated UAV on-station availability should be provided on a visual timeline (D2, D3) - Uncertainty of estimated timeframes should be indicated on availability timeline (D2, D3) - Potential missed communications points (D2, D3) - Future likely UUV tracks (D2, D3) - Vehicle limitations (when predicted to exceed some safe region) (D3) - UUV schedules (D2, D3) - Prediction of system health/status (D2)
	- UAV MTI imagery (D4, P2) - UUV target imagery/sensor data (D4,	- MTI exploration capabilities (playback, zooming) (D4, L3, P2)	- Uncertainty of predicted target location should be displayed

Figure 2.3 – Situation Awareness Requirements – Excerpted from Nehme et al., 2006

2.2.4 Decision Ladders

In this step, the main critical decisions identified in the event flow diagram (step 2) are studied in detail (Nehme et al., 2006). Decision ladders (Rasmussen, 1986) are used to depict the decision processes and to understand the necessary information and the states of knowledge that must be reached in order to accomplish the decisions.

Currently in the hybrid CTA the decision ladders step only generates a single set of decision ladders for a typical task operator (e.g., Figure 2.4). However often in the team environment, there would be multiple decision processes of different operators responsible by different task roles related the same event in the event flow. This research explores the expansion of this decision ladder step to capture multiple team member decision making, the following section describes the decision ladder concept in more detail.

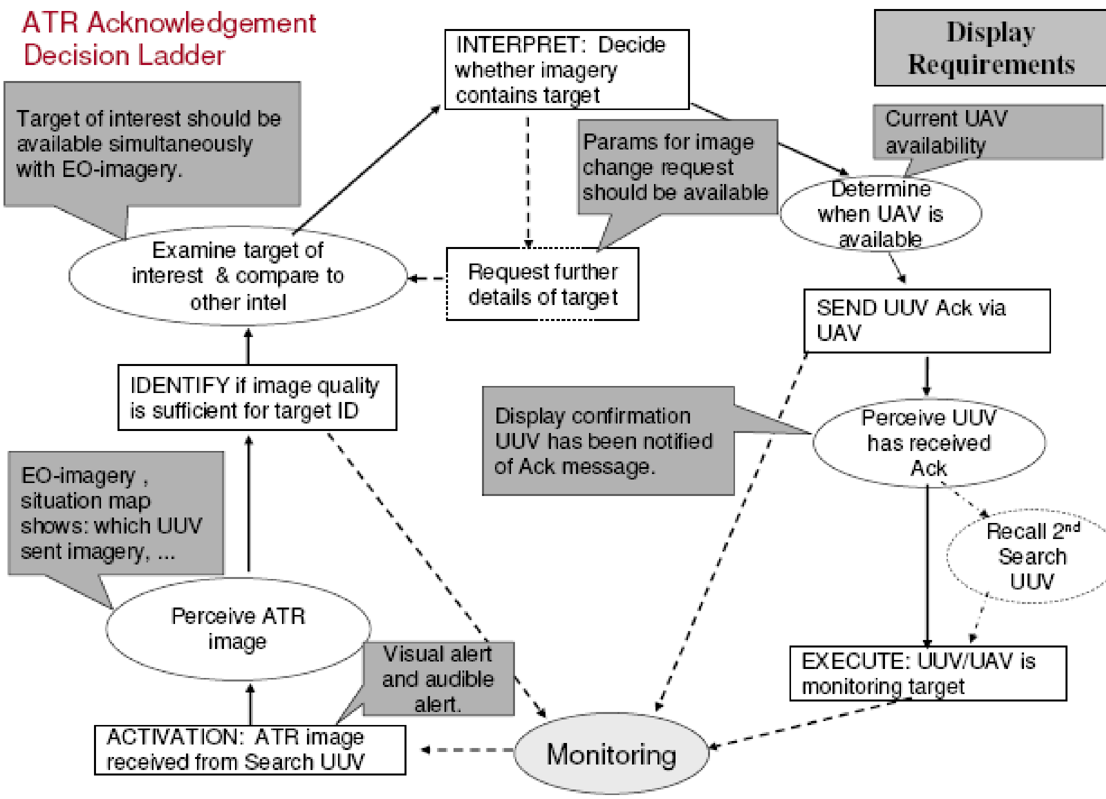


Figure 2.4 – Decision Ladder (this decision ladder has been augmented with corresponding display requirements – shown in gray boxes) – Excerpted from Nehme et al., 2006

2.3 Decision Ladders in Detail

According to Pharmer (2004) a decision ladder describes human information processing in response to information from the environment. It depicts relationships between the levels of cognitive control (human behavior) and decision phases.

Rasmussen (1986) first described the sequence of steps involved in a decision ladder (Figure 2.5), using the example of a power plant control room:

> "First, the decision maker has to *detect* the need for intervention and has to look around and to *observe* some important data in order to have directions for subsequent activities. He or she then has to analyze the evidence available in order to *identify* the present state of affairs, and to *evaluate* their possible consequences with reference to the established operational goals and company policies. Based on the evaluation, a *target state* into which the system should be transferred is chosen, and the task that the decision maker has to perform is selected from a review of the resources available to reach the target state…When the task has thus been identified, the proper *procedure*, i.e., how to do it, must be *planned* and *executed*."

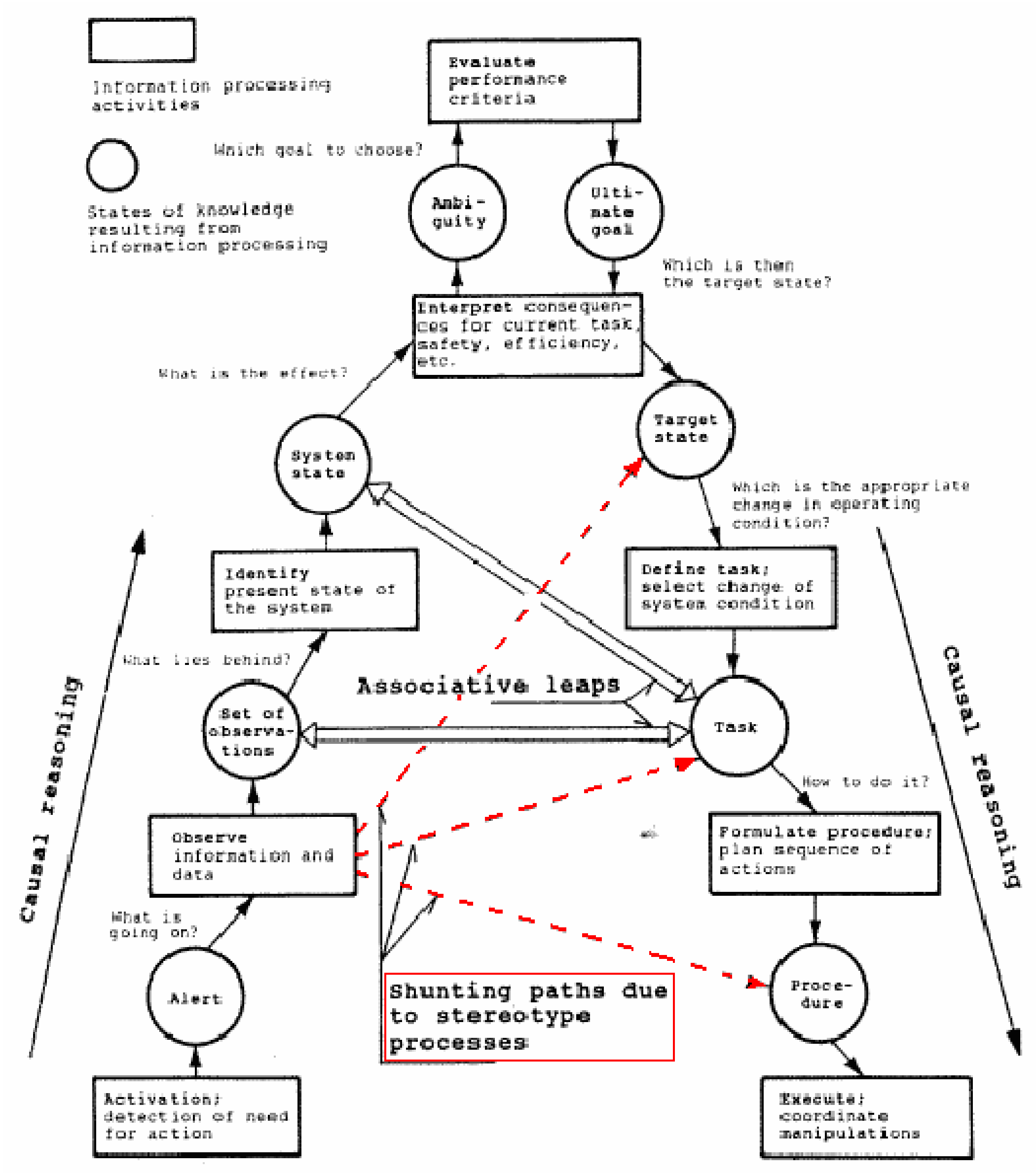


Figure 2.5 – Decision Ladder – Adapted from Rasmussen, 1986.

The boxes in the ladder illustrate the information processing activities involved in each decision phase and the circles represent the knowledge states reached through information processing. The left hand side of the ladder consists of analysis, or situation assessment. The right hand side consists of planning, or response selection.

The main difference in relation to other models is that the model is able to shortcut through the different stages (Holt et al., 1992). These shortcuts are represented by dashed red arrows in Figure 2.5. It is well established in the literature that human decision making is often characterized by the use of heuristics, or shortcuts to decision making processes such as availability and representativeness (Pharmer, 2004).The shortcuts can occur in two ways: first, if a response is very well rehearsed, little processing is necessary, a stimulus-response situation; second, if there is insufficient time for detailed processing (Holt et al., 1992).

2.4 Boundary Objects

Lee (2007) described the boundary objects as an important innovation in collaboration and information practices studies.

Star (1989), who conducted studies of distributed work in scientific communities, used the term boundary object to characterize artifacts that were shared by different communities of practice, with different purposes, in order to coordinate joint activities. A boundary object is defined by Star & Griesemer (1989) as:

> "an analytical concept of those scientific objects which both inhabit several interacting social worlds … and satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly constructed in common use, and become strongly structured in individual-site use. These objects may be abstract or concrete."

Researchers have employed the concept of boundary objects for several purposes (Lee, 2007). For example: Larsson (2003) used the boundary objects to show that a single artifact can be shared and used by different people with different purposes; Pawlowski and Robey et al. (2000) used the concept to discuss systems of information between communities of practice.

Research has shown that boundary objects are both an important and flexible concept in teamwork studies, because they contain sufficient details to be understandable by different team members who are responsible for different tasks, yet none of them must understand the full context of the use by the other members (Prasolova-Førland, 2003). Therefore, the use of boundary objects allows the analyst to design system interfaces that provide the necessary information for a party to execute his/her activities, individual or collaborative, without drowning in unnecessary details that could overload him/her (Halverson and Ackerman, 2002).

As boundaries, boundary objects link the reference points of different team members and focus the analyst's attention on the multiple relationships that exist in collaborative work rather than on the object itself (Baker, Jackson and Wanetick, 2005).

A research conducted by Star (1989) summarizes the benefits of studying the boundary objects in three items. In her observations she claimed that boundary objects made cooperation possible because participants:

> "(1) cooperate without having good models of each other's work;
>
> (2) successfully work together while employing different units of analysis, methods of aggregating data, and different abstractions of data;
>
> (3) cooperate while having different goals, time horizons, and audiences to satisfy."

In the current Hybrid CTA method there are not specific steps where the analyst investigates if aspects, such as the ones listed above, are being achieved. Thus, an operator's interface designed using the Hybrid CTA, misses important collaborative features. For this reason, we decided to include the study of the boundary objects in the proposed Hybrid CTA extension that will be developed in this work.

Chapter 3 The Hybrid CTA Collaborative Extension

As previously described, this research aims to develop a method that addresses the limitations of the Hybrid CTA, which supports the generation of requirements for systems design focused on coordinative and collaborative aspects. This chapter presents the proposed method. The Hybrid CTA Collaborative Extension method consists of several main steps beyond the basic Hybrid CTA. This chapter describes each step in detail.

The proposed method consists of the following steps:

(1) Apply the basic Hybrid CTA method (See Chapter 2);

(2) Create role-specific decision ladders;

(3) Create a unified “team decision ladder”, called the Collaborative Decision Process Diagram (CDPD);

(4) Identify boundary objects and their informational requirements;

(5) Identify the information relationships between boundary objects;

(6) Coalesce the final information requirements.

The following sections describe these steps in detail.

3.1 Hybrid CTA application

This step consists of conducting a basic Hybrid CTA, as detailed in Chapter 2.

3.2 Role-Specific Decision Ladders

Although decision ladders are part of the Hybrid CTA, in this extension of the method, a new approach and some modifications on the original decision ladder’s model (Rasmussen, 1986) are proposed.

First, it will be assumed that if there are different critical decisions taking place during the task execution, there must a decision ladder for each of them. Also, if different team members make individual critical decisions that affect the team tasking, there must be different decision ladders for each team member’s decision. The intention of this approach is to explore in detail the individual decisions in order to comprehend: their context in the overall task, the existence of relationships between different decisions, which team members’ decisions are dependent upon the decisions of others and the outcome of these decision dependencies.

Second, since this work aims to study and support collaboration between team members, it may be necessary to change the original Rasmussen's 8-step decision ladders when the analyst notices that important aspects of coordination are being hidden in a single step of a team member's decision ladder. To overcome this issue, it may be necessary to break a single step into several sub-steps as necessary in order to detail the interactions completely. To illustrate this idea, an example is presented in Figure 3.1. In this example, an operator is in the last step of a decision ladder, the "execute procedure" step. It can be noticed that there are many steps, some of which involve interactions between operators, hidden in the execute procedure step (details about the information contained in the steps and in the sub-steps will be explained in the following chapters).

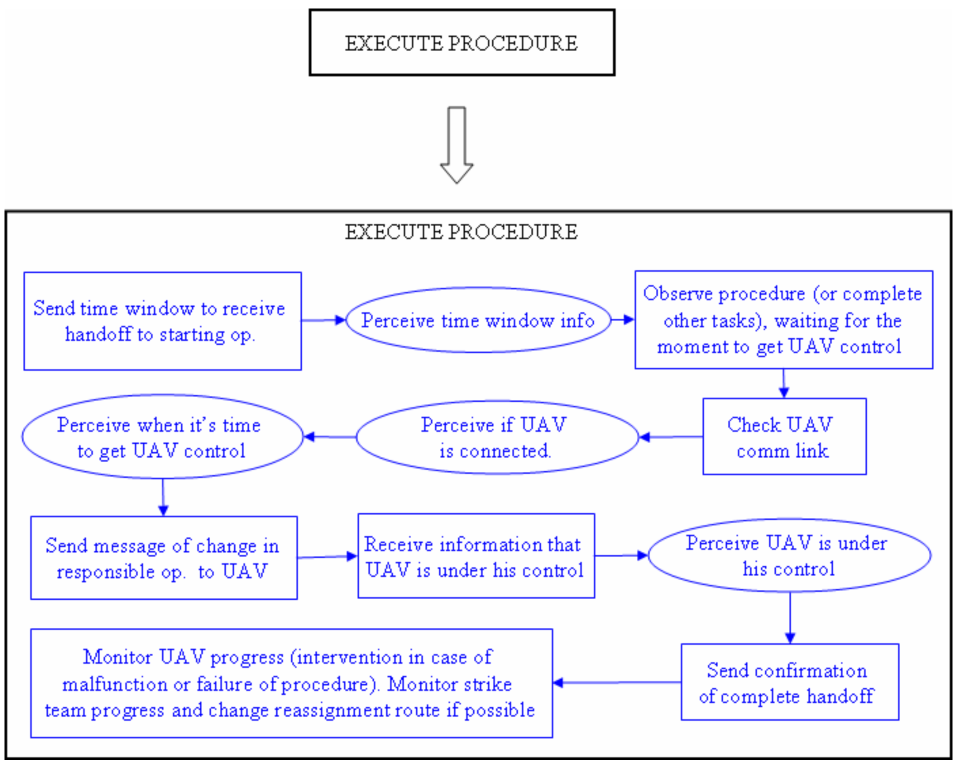


Figure 3.1 – Breaking steps of the original decision ladder to capture hidden coordination aspects

The decision ladders' building process may also consider the "decision ladders' shortcuts" concept proposed by Rasmussen (1986). A shortcut means that some steps of the decision ladders may be skipped for some team members involved in the joint work. This approach should be used when the analyst notices that the decision being studied is too simple or immediate to require a complete decision ladder. An example of a shortcut is given in Figure 3.2. In this example, an operator is executing a task that does not require a complex decision or a plan of execution to be made. Thus, a shortcut takes the operator from a condition where he/she has adequately identified the relevant information from the scenario to a point where he/she is supposed to execute a certain procedure.

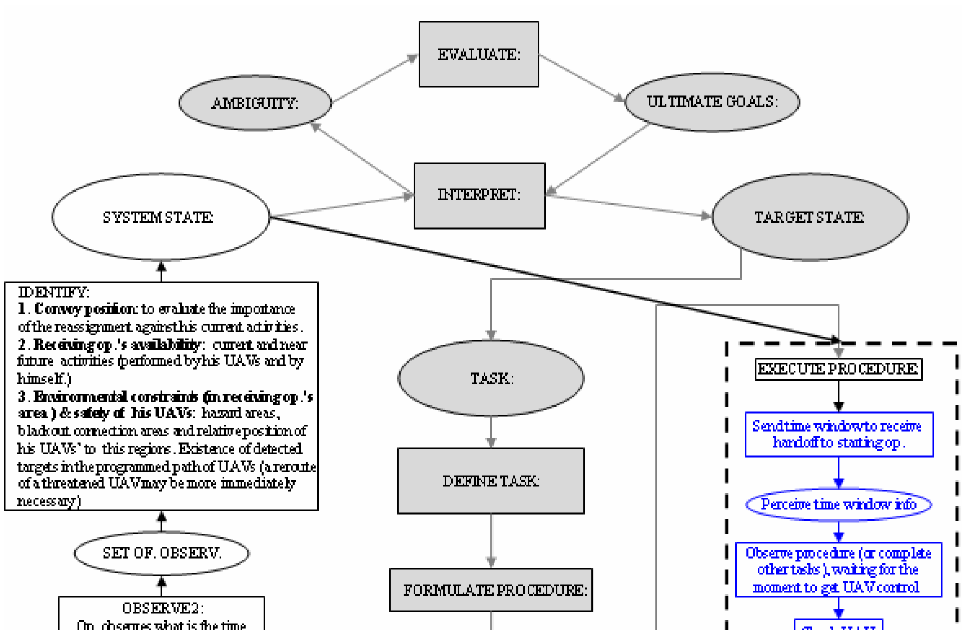


Figure 3.2 – Decision ladder's shortcut

3.3 Collaborative Decision Process Diagrams (CDPD)

This step involves the construction of a combined graphical representation that illustrates the connections between the different individual decision ladders. This approach of putting together decision ladders of different actors involved in a certain task was first proposed by Vicente (1999) in his book on Cognitive Work Analysis. The difference between Vicente's approach and the approach presented in this report is that Vicente was analyzing a decision process that happened in a certain sequence and different actors were executing their tasks in series with the others (e.g. one operator executed the first three steps of the decision ladder and then another operator executed the last five steps). The approach adopted in this work is to analyze decision processes in which different actors execute their tasks in parallel, i.e., more than one person may influence single steps of a decision ladder.

After jointing the decision ladders, a walkthrough from the activating step of the first decision to the final step of the last decision in the task is done. This walkthrough is built through a sequence of diagrams that represent the gradual evolution of a certain operation as decisions from different team members are being executed. This graphical representation gives not only a notion of possible interactions between different decision processes (and possibly between the different team members responsible for these decisions) but also presents the temporal constraints involved in or created by these interactions.

3.4 Boundary Objects

The concept of boundary objects has been used by different branches of research (Lee, 2007) to show that different people may use the same object with distinct purposes (Larsson, 2003), to build theories about information systems as boundary objects between communities of practice

(Pawlowski et al., 2000), and to explore activities surrounding boundary objects within the flow of information (Mambrey & Robinson, 1997; Lutters & Ackerman, 2002).

Based on the fact that boundary objects are described as objects that coordinate the perspectives of various communities of practice (Wenger, 1998; Henderson, 1999) they were used to define the relationship between different team members' decision making processes in this proposed Hybrid CTA extension. The study of boundary objects will be the initial approach used to support the generation of requirements focused on team collaboration and coordination.

This step consists of inspecting the existence of boundary objects being shared along the task. If any boundary objects are found, they are studied in detail so that all the possible states they may be in are understood, as well as the consequences of each involved team member comprehension or miscomprehension of these states.

Once the boundary objects' roles and states are well understood, a list is generated containing all the possible information that can be extracted from each boundary object in each possible state.

3.4.1 Information Components

"Boundary objects can be used with different purposes by different people" (Larsson, 2003).

This quote evidences the possible existence of different informational needs about the same boundary object, depending on the task role of each team member.

Thus, it was decided to study how each team member should see the boundary objects, in terms of information components requirements, so that team members would be supported to accomplish their own sub-tasks while being able to coordinate with other team members.

In this step, the CDPD is used so that walkthroughs are made. In each walkthrough a single boundary object is analyzed and, for every step of the CDPD, a list of the necessary information about this object is made for each team member. For example, suppose a certain boundary object contains three elements of information: "x", "y" and "z". Now suppose that the there are two team members: "A" and "B". The process starts on the first step of the CDPD. In this step, for example, the analyst may define that the team member "A" needs to know "x" and "y" about the object and that the team member "B" needs to know "y" and "z", according to the task they are executing. The process is repeated for the second step of the CDPD, then for the third and etc. until every step of the CDPD is studied. Then, the analyst picks another boundary object, and the whole process is repeated.

Table 3.1 – Example of the information obtained after a complete CDPD walkthrough for the boundary object 1

Boundary Object 1	CDPD Step	Team Member A	Team Member B
Information	1	x, y	y, z
	2	x	x, z
	…	…	…
	n	y, z	y

3.4.2 Levels of detail

The study of the information components gives the notion of which information must be given to each team member. However, this notion is incomplete in the sense that it does not give an idea of the detail necessary for the user in the context of the task he/she is executing. For example, in a route planning task for a vehicle, it is important to know detailed information about the available fuel in order to define if a choice is feasible. However, if a person is only monitoring the execution of a planned route, he/she will only need information about the fuel if something critical happens, for example, if the tank is damaged and fuel is being lost fast.

It is essential for an interface designer to understand the tasks each team member will execute in a way that the amount of detail that must be supplied for each information component can be well defined. This is especially critical in a multi-task scenario, where information supply must be well balanced so that it does not disturb or overload operators (excess of information) nor is it too superficial (lack of information).

Thus associated to each item of the previous step a classification is made of the level of detail of information required by each team member about each boundary object, in each step of the CDPD.

As illustrated in Figure 3.3, three possible levels of detail of information were defined:

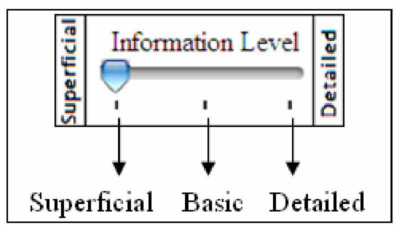


Figure 3.3 – Slider with the levels of detail of information

- Superficial Info – Abstract, qualitative information, gives only a higher level notion of the object it describes.

- Basic Info – It can be abstract and qualitative or quantitative (e.g. an estimated time). It provides more information than the superficial info level, but still not particularly detailed. In a decision making process it is the kind of information that helps the team member to exclude obviously problematic choices and understand the problem enough to know what kind of information he/she will need to see in detail in further steps.

- Detailed Info – It can be quantitative or well described and explained qualitative information. It is, as the name says, detailed, refined information, and it makes the real difference in evaluating and interpreting options in order to reach a final decision. This level of information should not be used unless it is strictly necessary to have a deep understanding of the object described since its usage can be very distracting and overloading.

3.5 Identifying Relationships

At this stage, there must be “x” copies of the CDPD, each of which contains the information components and the level of detail for each one of the “x” detected boundary objects, in each step of the ladder, for each team member.

When complex decisions must be made in a scenario with a considerable number of boundary objects, studying each boundary object information components independently may be a narrow focus. There may be dependencies that could give strong support to coordination and to decision making processes hidden in the lack of connection between the boundary objects.

For this reason, it was decided that at this point the analyst should put all of the information about the different boundary objects contained in each CDPD together in a single CDPD, so that relationships between the information contained in the boundary objects (in the same one and in different ones) can be identified.

If the task is complex enough so that the text information put together makes it difficult to locate relationships, an alternative approach is suggested, which consists of creating graphical representations, such as small icons, of each component of information and finding the relationships graphically. Note that this graphical representation is optional, and may be chosen to be used or not according to the analyst’s preference.

3.6 Summarizing Requirements

This step consists summarizing the collaboration and the coordination informational requirements for the user interfaces to support each team members’ tasks based on the Hybrid CTA application (situation awareness and decision ladders requirements), based on the information contained in the boundary objects (with the correspondent levels of detail) and on the relationships found between the information components of the boundary objects. From the information obtained, a table of design requirements is created.

Chapter 4 Application of the Method to a Representative UAV Team Task

This chapter presents a case study to validate the method presented in the previous chapter. The new method will be used to generate the functional and information design requirements for operator displays to support team members in a futuristic UAV mission task.

A representative UAV team task scenario was developed in which a number of operators work together to secure a large geographic area (team's area of interest (AOI)) to ensure the safe passage of an important political convoy that will be traveling through the area in the near future.

The region, through which the convoy is supposed to go, may contain enemy threats (initially unknown) and is monitored by a number of semi-autonomous unmanned aerial vehicles (UAVs) provided with cameras (which are supposed to detect and acquire imagery of threats as they surveil the region for targeting purposes).

When the convoy starts the mission, the presence of threats across the entire region is unknown, and, as the time goes by, and the UAVs develop their surveillance activities, the region becomes gradually revealed so that areas free from threats become well defined as the threats are detected by the UAVs and identified by the operators. Once hostile threats are identified, the team must coordinate with an external strike team to target and destroy these hostile contacts before they are within weapons range of the convoy. Once these threats are identified, they will be referred to as targets.

The team involved in this UAV team task consists of three UAV operators, each responsible for controlling multiple UAVs and one mission commander overseeing the team's mission progress.

The operators are responsible for supervising the surveillance progress of several UAVs under his/her control in the AOI, for classifying the targets detected by any of these UAVs, and for coordinating with a strike team to destroy the targets. Operators are in charge of sending or receiving a UAV to or from another operator (responsible for another AOI) whenever the mission commander requests for a reassignment. The reassignment task involves re-tasking a UAV from one AOI to another. This activity involves negotiating time constraints and availability with the stakeholders and making sure that the UAV plan modifications do not violate any operational constraints. Operators are also responsible for executing any requested reroute of the UAVs inside their own regions (e.g., to enable a UAV to avoid an active target).

The mission commander is responsible for monitoring the mission, for ensuring the safety of the convoy, for managing the workload of the UAV operators, and for making decisions about critical and off-nominal events that may occur during the mission. To accomplish these objectives the mission commander may request that the convoy hold its current position if its intended path is not deemed safe for passage, request supplementary surveillance data from a nearby joint surveillance and target attack radar system (JSTARS), and request the re-tasking of one of the team's UAV assets to a different sub-AOI (requiring the handoff of the UAV asset between operators).

While there are many collaborative components to this UAV team task, this case study will be dedicated to the decision-making and performance of the multi-UAV operators managing the progress of UAVs and re-tasking their UAVs when requested. More specifically, the focus of this study will be to apply the extended Hybrid CTA to obtain informational requirements for a reassignment task. The choice to focus on this specific task was made because it is one of the most critical operations in terms of coordination and collaboration during the mission execution phase.

The four steps associated to the original Hybrid CTA were first conducted for the whole execution phase in order to identify the critical decisions and task event flow associated with the previously described UAV team task. The full details of this Hybrid CTA are provided in Appendix A. Table A.1 presents the scenario task overview, Figure A.1 illustrates the event flow diagram, Table A.2 presents the situation awareness requirements, Figure A.2 illustrates the single decision ladder associated with the UAV reassignment task, from the UAV operator's perspective.

The next step was to then expand this original Hybrid CTA, and, in particular, the decision ladder shown in Figure A.2 to represent the multi-faceted decision making process across the team relating to this specific collaborative task activity.

4.1 The Hybrid CTA Collaborative Extension

The UAV reassignment task was selected for this case study, since it is an activity that involves decisions from different team members and interactions between operators and between operators and the mission commander. It is the kind of activity where coordination and collaboration aspects are essential, and thus, where the limitations of the Hybrid CTA method for team design would be more evident.

Since the focus has been narrowed from the mission execution phase to one of its specific sub-phases (Figure 4.1), it is necessary to zoom in the details of the reassignment sub-task before continuing. For this reason, a new event flow diagram was created (Figure 4.2), with the intention of giving a better idea of the chronological organization and the actors' roles related to the reassignment task.

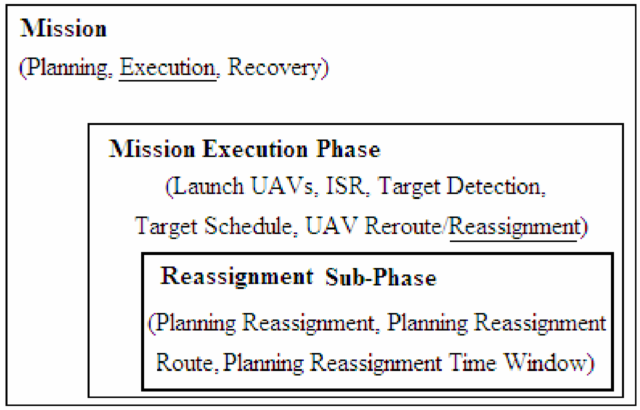


Figure 4.1 – Current Focus

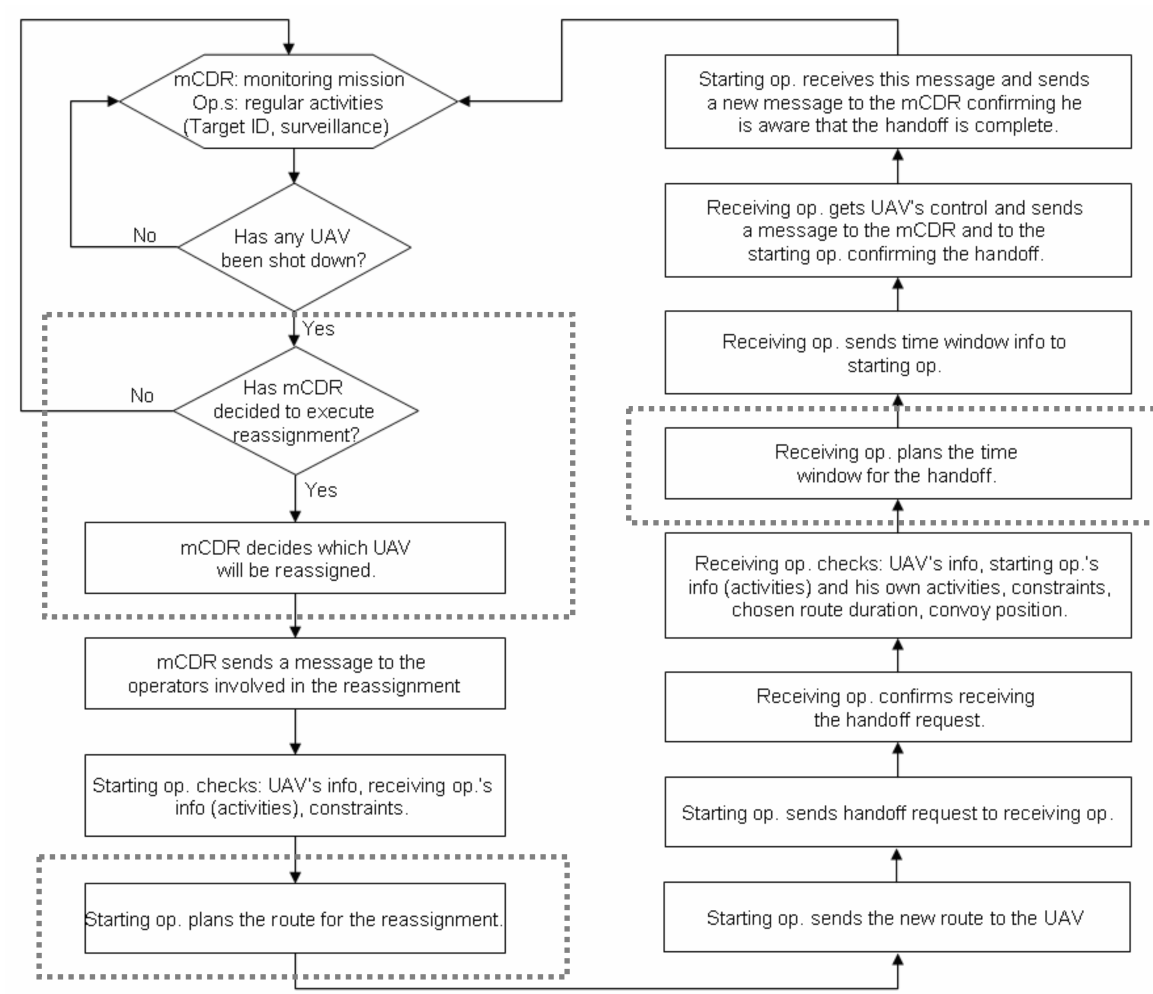


Figure 4.2 – Reassignment Event Flow Diagram

This study will be based on a reassignment task, after a UAV has been shot down. When a UAV is shot down, the mission commander must decide whether or not he/she will reassign another

UAV to that region and must also choose a UAV for the reassignment if it is supposed to happen. When the mission commander completes his decisions, he/she notifies the two operators who will be involved in the task (the one who controls the UAV chosen for the reassignment or "starting operator", and the one who was controlling the shot down UAV or "receiving operator").

Once this notification is received, the starting operator starts planning the routes for the reassignment. The starting operator defines at least two possible UAV routes: a nominal route (finishing exactly where the UAV was shot down) and a safety route (finishing outside the range of the target that shot down the UAV).

When the routes are planned, the starting operator uploads them to the UAV and sends a handoff request to the receiving operator. The receiving operator is responsible for deciding when he/she is receiving the UAV control.

Once the handoff occurs, both operators notify the mission commander and the task ends.

4.1.1 Role Specific Decision Ladders

The events delimited by doted lines in the event flow diagram (Figure 4.2) involve three critical decision processes: deciding whether or not to reassign a UAV and which UAV to reassign (mission commander), deciding what should be the reassignment route (starting operator) and deciding when the handoff of the UAV control should take place (receiving operator). These decisions will be expanded in the following role specific decision ladders for their respective actors.

Notice that, as discussed in Section 3.3, standard decision ladders are modified in order to expand steps where it is noticeable that collaborative aspects are hidden. Each of these expanded steps will be indicated by dotted lines in their respective decision ladders.

In the following decision ladders, the rectangles represent data processing activities and the circles represent states of knowledge resulting from data processing.

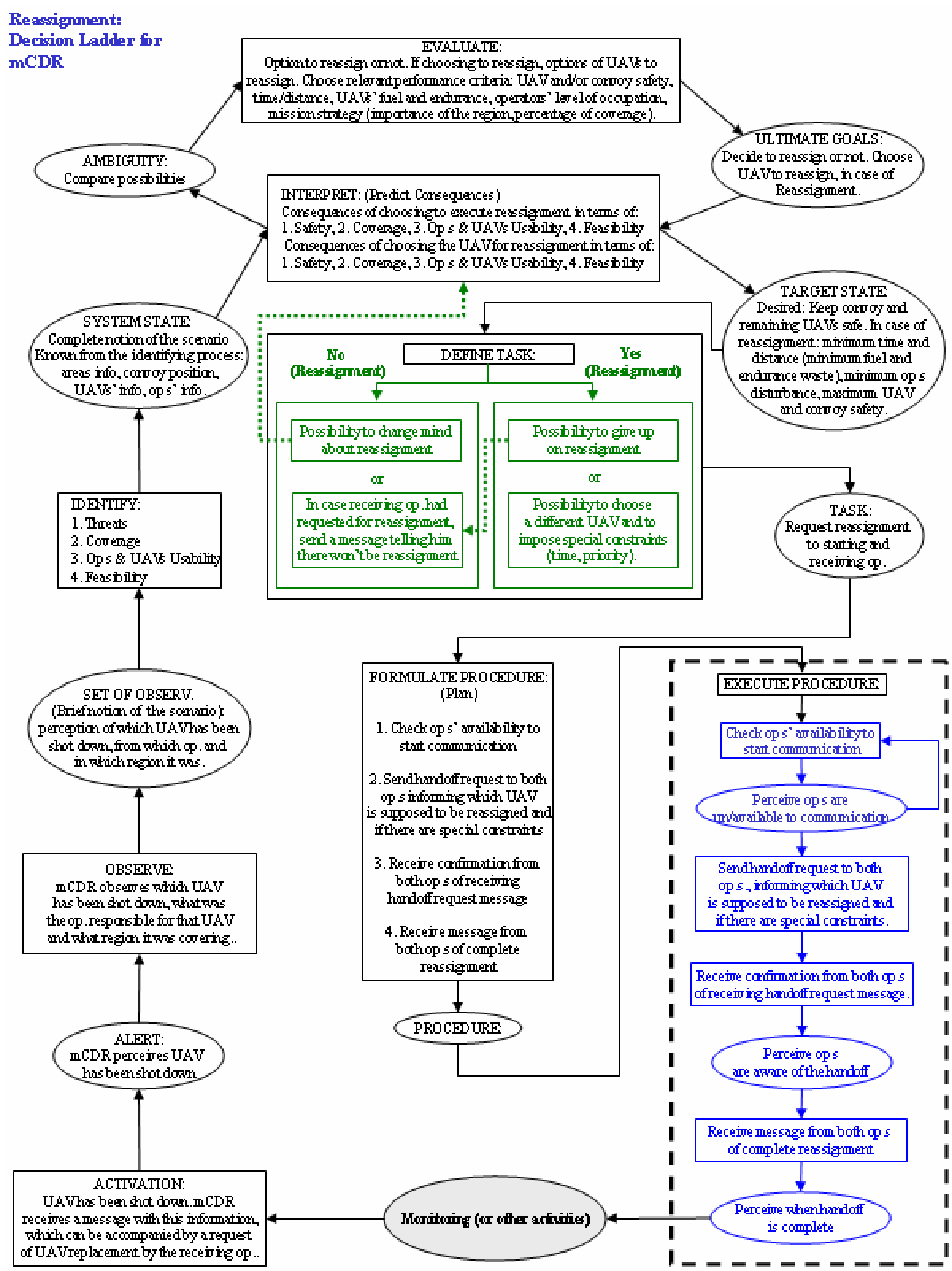


Figure 4.3 - Mission Commander's Decision Ladder

Figure 4.3 presents the mission commander's decision ladder. The mission commander is activated when a UAV is shot down. The activation step consists of learning the existence of the problem: a shot down UAV. The activation information can be accompanied by a request for reassignment from the receiving operator if he/she understands it is essential and immediate for the mission success.

The mission commander perceives the activation and starts the observation activity, where he/she acquires a better, yet still rough, notion of the problem. In the "observe" activity, the mission commander finds out which UAV has been shot down, who was controlling the shot down UAV and which region the shot down UAV was covering.

Once the mission commander perceives this set of observations, he is able to enter the identification process. In the "identify" step the mission commander learns more information about the problem and what the scenario is (the detailed information that must be acquired by the mission commander in this step is presented in the Appendix B.1.1).

At this point, the mission commander has a complete notion of the scenario. The following step is the "interpret" activity. It consists of predicting the consequences of making a decision.

Since the mission commander must not only decide if the reassignment will occur, but must also pick a UAV for the reassignment task, the consequences of both decisions must be predicted (the aspects that must be involved in the mission commander predictions are presented in the Appendix B.1.1).

Once the predictions from the "interpret" activity have been made, the mission commander has a defined set of options and is able to compare the possibilities of choices by entering the "evaluate" step. In the "evaluate" step, the mission commander reduces the possible options by choosing the relevant performance criteria to be adopted in the final choice. In this step he/she compares the options to reassign or not. If choosing to reassign, there are options of UAVs to reassign. The mission commander must then choose relevant performance criteria for the choice of the UAV: UAV and/or convoy safety, time/distance, UAVs' fuel and endurance, operators' busyness, mission strategy (importance of the region, percentage of coverage). By choosing the criterion or criteria to be adopted, a final choice can be made.

After the choice was made, the mission commander re-enters the "interpret" step in order to check if the decision really satisfies constraints and is feasible and safe. If this last check confirms the decision is adequate, the mission commander leaves the top of the decision ladder with a final decision. He/She must then acquire a new state of knowledge where the "target state" is defined. The target state is an ideal state, which may be impossible to reach, however it contains the idea that must be kept in mind during the next steps (while planning the execution of the decision). The target state for the mission commander decision is to keep the convoy and the remaining UAVs safe. And in case of reassignment, the target state is to execute the reassignment with the minimum time and distance (minimum fuel and endurance used), with minimal operator disturbance, and with maximum UAV and convoy safety.

Minor changes in the final decision can be made in order to get closer to the target state. However, since the decisions performed by the mission commander are "binary" (reassign or not and choose UAV A or B for the reassignment) if changes are made, they are not really insignificant, which means that during the planning, the decision may be completely changed. Thus, the "define task" step has a shortcut to the top of the ladder, which allows the mission commander to change his mind about the decision he/she was carrying.

The next step consists of formulating the procedure, which means defining how the mission commander will execute the task. Finally, the last step consists of executing the formulated procedure. Details about these steps can be seen directly in the decision ladder. Notice that the execution of the procedure was expanded in sub-steps so that the interactions with the operators can be adequately shown.

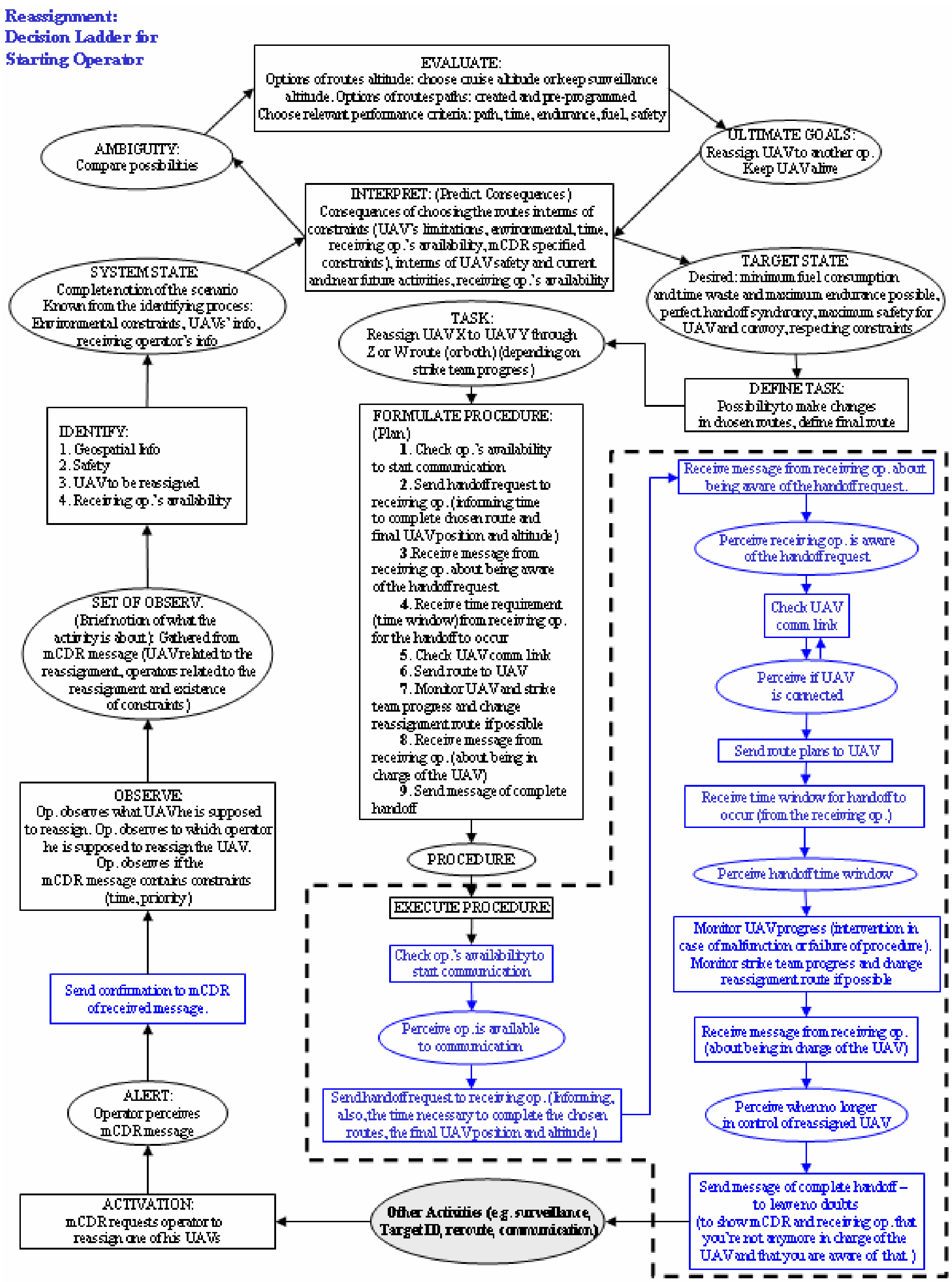


Figure 4.4 - Starting operator's Decision Ladder

Figure 4.4 presents the starting operator's decision ladder. The starting operator is activated by the message from the mission commander requesting the reassignment of one of his UAVs. The starting operator perceives the mission commander message, and sends a confirmation of receiving it.

At this point, the starting operator enters the “observe” step. In this step he/she observes what UAV he should reassign, to which operator he should reassign the UAV and if the mission commander message contains any constraints (e.g. time or priority). Perceiving this set of observations, the starting operator enters the “identify” activity. The detailed relevant aspects to be identified by the starting operator are presented in the Appendix B.1.2.

The next activity is the interpretation (prediction of consequences) of the possible route choices: consequences of choosing the route in terms of constraints (UAV’s limitations, environmental, time, receiving operator’s availability, mission commander specified constraints), in terms of UAV safety and activities (current and near future ones) and receiving operator’s availability.

Once the options are interpreted and compared, the starting operator enters the “evaluate” step, where he/she must compare the possible routes based on chosen performance criteria (e.g. path length, time, endurance, fuel, safety).

Since the “ultimate goal” is to reassign the UAV keeping it alive, the decision that comes out from the “evaluate” step must be checked by re-entering the “interpret” state.

The “target state” for the starting operator’s decision is to reassign the UAV with minimum fuel consumption and time waste and maximum endurance possible, perfect handoff synchrony, maximum safety for UAV and convoy, respecting constraints.

With this state in mind, the task is defined and the procedure is formulated. The last step consists of executing the formulated procedure, and, once again, it is broken, so that the coordination of the handoff with the receiving operator could be adequately represented.

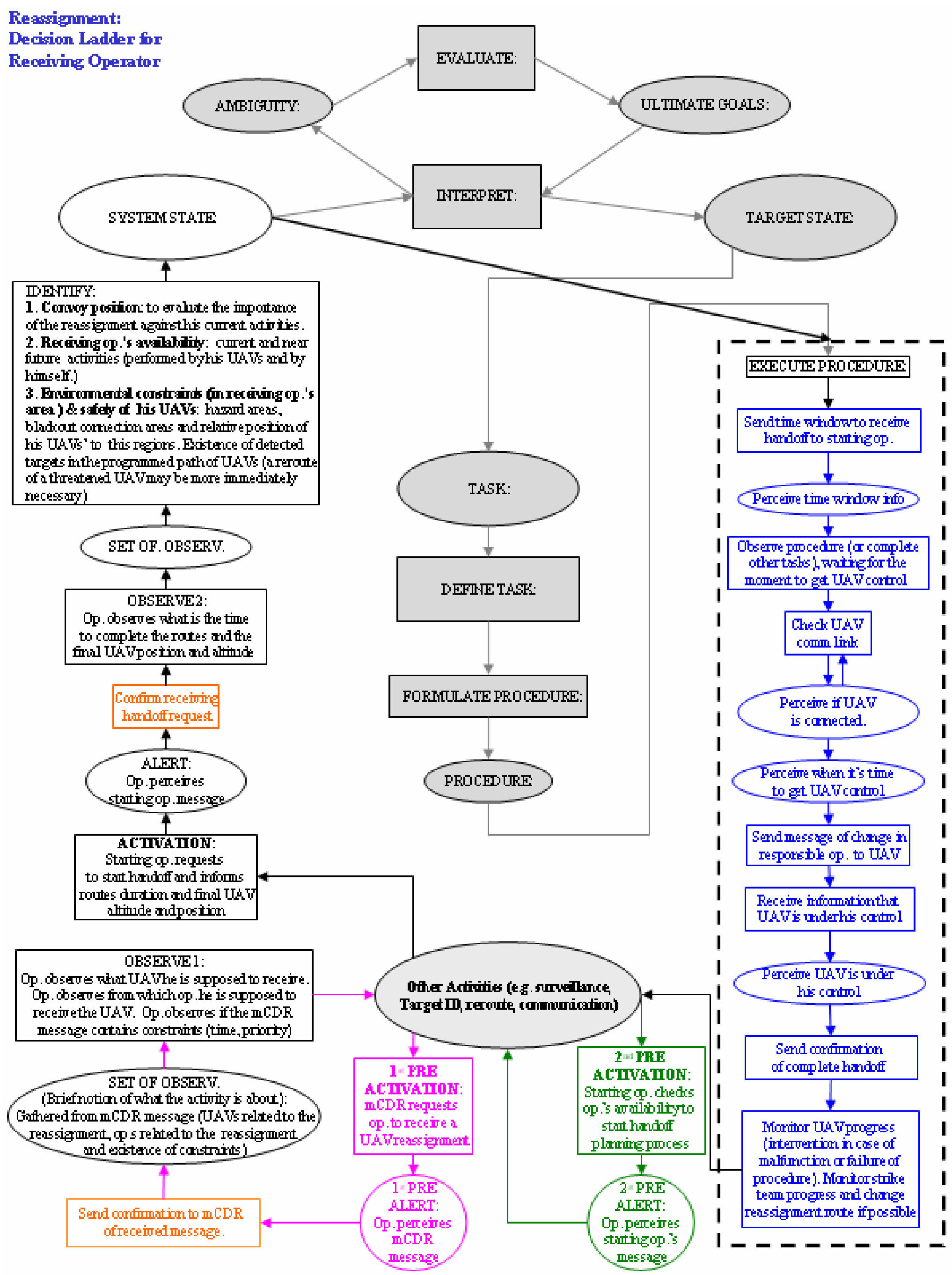


Figure 4.5 - Receiving operator's Decision Ladder

Figure 4.5 presents the receiving operator's decision ladder. This is a simpler decision ladder, compared to those of starting operator and mission commander, where many steps of the ladder are not utilized.

The receiving operator gets two pre-activations before the main decision ladder steps are activated. The first activation is the message from the mission commander requesting the UAV reassignment. The mission commander message informs which UAV he/she is supposed to receive and also if there are constraints of time and priority involved in the task. The second activation is a message from the starting operator confirming he is starting to plan the possible reassignment routes.

The effective activation is the request for the UAV handoff, sent by the starting operator right after he/she has uploaded the plan to the UAV. This activation leads the receiving operator to observe what the time to complete the route is and the final UAV position and altitude.

The information related to the "identify" step for the receiving operator is detailed in the Appendix B.1.3.

Notice that a part of the receiving operator's decision ladder has been represented in gray and was skipped by a shortcut that goes from understanding the scenario to the effective execution of the handoff. The steps in gray were neglected because it is assumed that the receiving operator's decision (when to get the reassigned UAV control) is too immediate and too simple to demand a complete decision ladder. Besides, in further analysis, it was noticed that the demand for information remained the same all along these gray steps, which confirmed suspicions that they were not relevant for the study. Once again, the execution of the procedure was broken in sub-steps, so that the coordination of the handoff with the starting operator could be adequately represented.

4.1.2 Collaborative Decision Process Diagram (CDPD)

In this step the decision ladders are unified. For the sake of simplicity, it was decided to use the original Rasmussen's decision ladder model (eight steps) as opposed to the expanded decision ladders. In this representation; however, the expanded decision ladders are used to inform the connections created between the items of the eight step model. Again for simplicity, only the data processing activities are represented here.

The decision ladders are stretched in straight lines and put together in the form of a diagram (Figure 4.6). The beginning (or activation) steps are located closest to the origin and the final steps are the ones at the extremities. The arrows represent expected interactions between team members in the steps (again, the expanded decision ladders are used to define these connections). This representation is obtained by studying the individual decision ladders looking for interactions.

Notice that this representation can be used to immediately determine where (along the steps) the flow of interaction is more intense, and, therefore, where the highest concern supporting collaboration should be.

Besides, since the steps of the decision ladders are explicitly represented, the CDPD can be used to conduct a step-by-step walkthrough of the team decision-making process to obtain a chronological notion of the order in which different events take place.

The interactions are represented by arrows (orange (dashed lines) for an interaction beginning and blue (dotted lines) line for an interaction ending) while internal processes (executed by an individual team member) are black (continuous lines); this gives a better notion of which steps are the most relevant in terms of collaboration and explicitly represents who is responsible by activating each interaction, thus detailing coordination aspects.

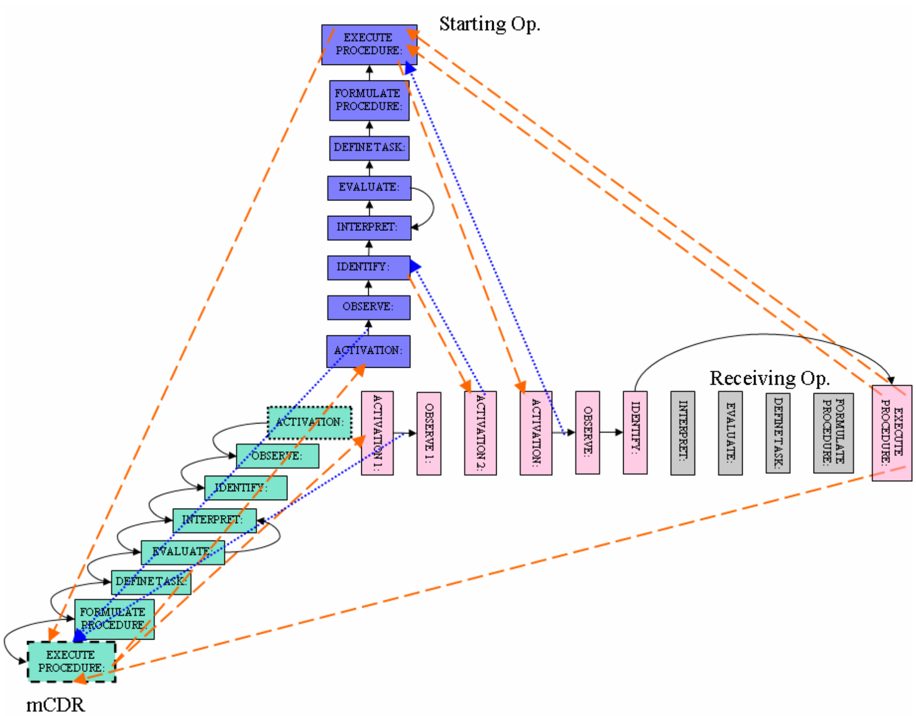


Figure 4.6 – Collaborative Decision Process Diagram (CDPD)

This CDPD representation (Figure 4.6) facilitates the understanding of the consequences of a failure in the information flow or in the interactions between team members. Next, a step-by-step walkthrough of the CDPD is conducted to facilitate the following steps of identifying the information requirements related to the team's critical boundary objects (Figure 4.7). A detailed walkthrough along the CDPD is presented in the Table B.1, Appendix B.2.

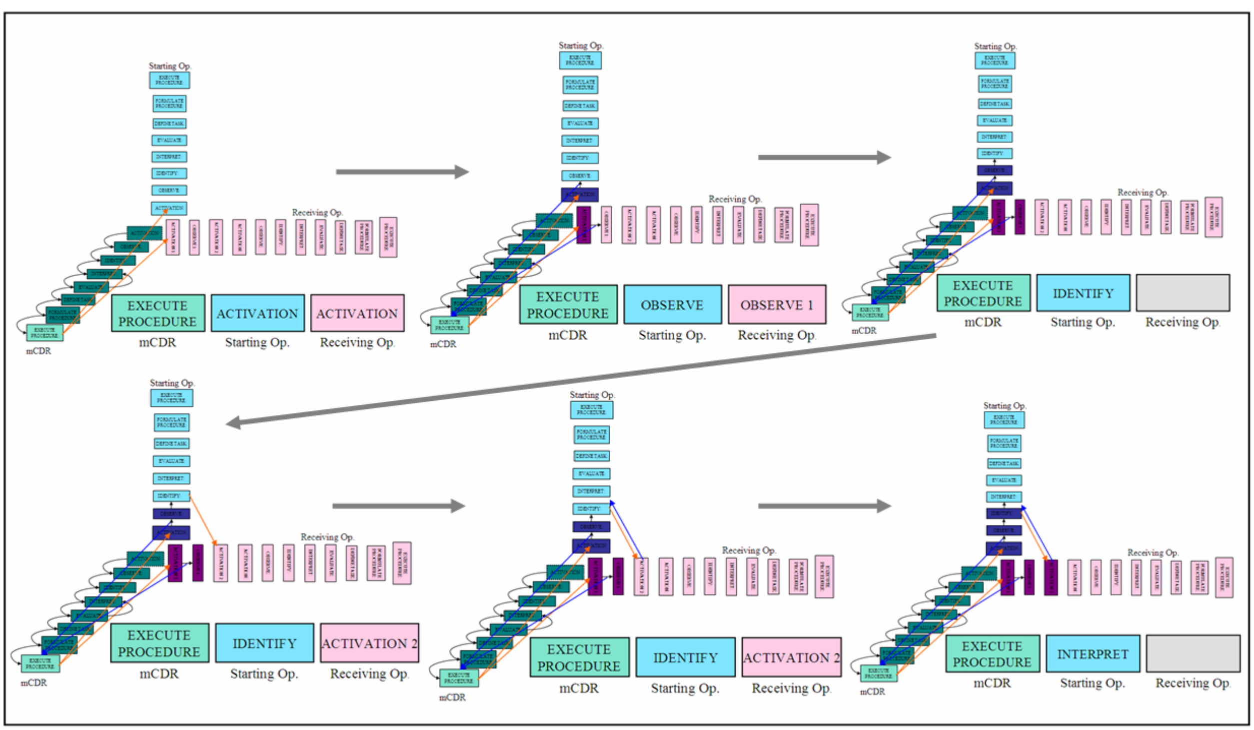


Figure 4.7 – Part of the step-by-step walkthrough process

4.1.3 Boundary Objects

This step presents the critical boundary objects being shared along the reassignment task. Three different boundary objects were found: the reassigned UAV, the convoy and the target that shot down the UAV. These elements are boundary objects because different team members, with distinct roles in the task, use and modify different pieces of the information contained in these objects while executing their activities and decisions. In this section, these boundary objects are studied in detail: their states are defined and the information they may contain are described.

Other boundary objects exist in this representative scenario (e.g. the other UAVs involved in the mission, the map, etc). However, it was decided to focus only on the three boundary objects which contained information most relevant to the collaborative aspects of the reassignment task. In developing a real system, an analyst will likely include more boundary objects (perhaps detailed at a more superficial level than critical boundary objects).

4.1.3.1 Reassigned UAV

The reassigned UAV is the boundary object whose relationship with the reassignment task is the most evident, since it suffers state modifications explicitly associated with the task execution.

The reassigned UAV may be in one of the three states presented bellow:

- **State 1: surveillance state -** the state the UAV is in when it is executing regular surveillance, searching for threats.

- **State 2: transiting state -** the state the UAV is in when going from one region to another (being reassigned, following the reassignment route).

- **State 3: non-steady state -** the state between surveillance and transiting (or vice-versa), a state in which velocity, altitude and route are changing.

Considering this definitions of states, it is possible to associate the reassigned UAV states to the steps of the reassignment task, as follows (Figure 4.8):

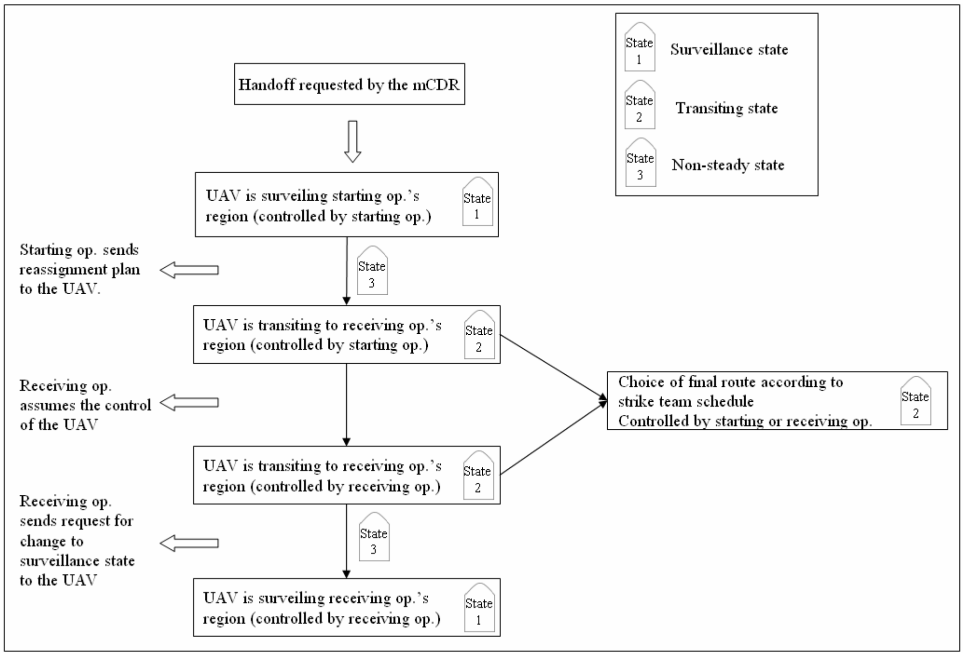


Figure 4.8 – Reassignment task and the UAV states

For each state, a list of possible information about the UAV was generated. These results are presented in Table 4-1 – Possible information about the reassigned UAV in each state.

Since the UAV is the most relevant boundary object for the reassignment task, the possible consequences of its state being misinterpreted by each team member was investigated, so that the consequences of a poor or confusing design could be understood. This is a way of knowing when and for whom the design is more critical, and, thus, avoiding breakdown failures. This investigation is presented in Appendix B.3 (Tables B.2, B.3 and B.4).

Table 4-1 – Possible information about the reassigned UAV in each state

Surveillance state	Transiting state	Non-steady state
- ATR on - Activity: Target ID or Regular Surveillance - Low altitude - Low speed - Surveillance route - Health status - Fuel status - Connection status - Operator in control of UAV - UAV number - UAV location - Estimated time to arrive at receiving operator's region (following a straight line at cruise speed) - Estimated time for the UAV to enter a target's range (if applicable) - Estimated time for change in control of the UAV - Estimated time to enter the range of the target that shot down the UAV	- ATR off - Activity: follow reassignment route ("on route") - High altitude - High speed - Reassignment route (nominal or safety) - Health status - Fuel status - Connection status - Operator in control of UAV - UAV number - UAV location - UAV's estimated time to arrive at receiving operator's region (following a straight line at cruise speed) - Estimated time for the UAV to enter a target's range (if applicable) - Estimated time for change in control of the UAV - Estimated time to enter the range of the target that shot down the UAV	- ATR off - Activity: Transition from reassignment/surveillance route to surveillance/reassignment route - Going from low/high to high/low altitude - Going from low/high to high/low speed - Health status - Fuel status - Connection status - Operator in control of UAV - UAV number - UAV location - Estimated time to arrive at receiving operator's region (following a straight line at cruise speed) - Estimated time for the UAV to enter a target's range (if applicable) - Estimated time for change in control of the UAV - Estimated time to enter the range of the target that shot down the UAV

4.1.3.2 Convoy

The convoy states are not directly dependent upon the reassignment task; however, these states may influence the team members' decisions and may create time pressure conditions.

The convoy may be in two main states: stopped or moving. If it is moving, it can be in three possible sub-states: out of range of a known threat, in range of a known threat, or in a potential threat range of an unsurveilled region. Table 4-2 presents the possible information about the convoy in each state and sub-state.

Table 4-2 – Possible information about the convoy

General information about the convoy (independent of the state):			
- Current health status and necessary health to get to the end of the team's region - Current fuel status and necessary fuel to get to the end of the team's region - Connection status - Convoy location (in the mission map context) - Convoy location (specific sub-region and correspondent operator) - Estimated time to arrive at next operator's region - Estimated time to get to the end of the team's region - Ideal time for convoy to exit the team's region - Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV - Estimated loss of health for crossing the threatened region that should have been surveiled by the shot down UAV - Estimated loss of time for stopping the convoy before entering the threatened region that should have been surveiled by the shot down UAV and waiting for the reassignment			
Stopped		**Moving**	
-	**Out of threat range region**	**In a target range region**	**In a potentially threatened region**
- Health loss since convoy was stopped - Elapsed time since the convoy was stopped - Estimated time to release convoy (if applicable)	- Estimated time to reach next known or potential threat envelop or region.	- Estimated loss of health in the target range region - Estimated gain in time for not stopping the convoy - Estimated time to leave the threat region (eg: the convoy gets out of the target's range region or the strike team destroys the target)	- Estimated loss of health in the threatened region (this can be estimated by a intelligence help team based on their knowledge of the probability of existence of targets in unsurveilled regions) - Estimated gain in time for not stopping the convoy - Estimated time to leave the potentially threatened region (e.g. a UAV surveils the region of the convoy gets out of the region)

4.1.3.3 Target that shot down the UAV

The target may be in one of theses three states: undiscovered, discovered and active, or destroyed. If the target is discovered and active, it can be in one these three sub-states: discovered but being classified, classified but not yet scheduled by the strike team, or scheduled but not yet destroyed (scheduled strike pending).

Table 4-3 presents the possible information about the target in each state and sub-state.

Table 4-3 – Possible information about the target

Undiscovered	Discovered and Active			Destroyed
-	**Discovered but being classified**	**Classified but not yet scheduled**	**Scheduled strike pending**	**-**
- Unknown information	- Threat location - Threat's region and correspondent operator - Elapsed time since target was detected - Team members involved in the threat classification (help requested) - Any information about the target (intell, imagery, etc).	- Target classification - Weapons range (aerial) - Weapons range (ground) - Target location - Target's region and correspondent operator - Target activity level (ground & aerial) - Elapsed time since target was identified - Elapsed time since information was sent to strike team schedule - Estimated time for the target to be destroyed (considering current and near future expected strike team schedule)	- Target classification - Weapons range (aerial) - Weapons range (ground) - Target location - Target's region and correspondent operator - Target activity level (ground & aerial) - Elapsed time since target was identified - Scheduled time for the target to be destroyed	- Destroyed target location

4.1.3.4 Information Components and Levels of Detail

For simplicity, the information components will be presented together with the levels of detail in the next section.

This step consists of defining the required information about the three previously defined boundary objects for each team member involved in the reassignment task in each step of the CDPD. However, to define this information, the state that the boundary object is in needs to be known, and, since the UAV is the only boundary object whose changes of states are directly associated with defined steps of the CDPD, special assumptions had to be made about each boundary object changes of state. The assumptions are presented in Table 4-4.

Table 4-4 – Special assumptions about boundary objects state changes

Boundary Object	UAV	Target	Convoy
Assumptions:	- The receiving operator assumes the control of the UAV when it is in the transiting state	- The target is classified and scheduled while the starting operator is planning the reassignment route. It is classified before the "interpret/evaluate" steps (in the starting operator decision ladder) take place and it is scheduled after these steps are complete. - The strike team destroys the target while the UAV is in the transiting state.	- The mission commander is receiving the information he needs about the specific sub-state of the convoy. We will only deal with the information that has connection with the UAV reassignment task.

The assumption that the handoff of control occurs in the transiting state was made for the following two reasons. First, the Automatic Target Recognition (ATR) will be off during the transiting state, so there is no danger of a target detection occurring close to the handoff time, thus, creating doubt of who would be the operator responsible for its classification. Second, the altitude, the route path and the velocity of the UAV are well known and approximately steady during the transiting state.

These assumptions are made about the target and about the convoy because it is believed that this is the hardest possible combination of events in terms of requiring cognitive effort from the team members.

The starting operator will have to plan the safety and the nominal route, since the target will not be destroyed before the route planning is complete. Besides, the target is classified before the route is planned, so the safety route may be accurately planned.

The target will be destroyed while the UAV is in the transiting route, thus, whomever is in control of the UAV at that time will be responsible for changing the UAV route (from the safety to the nominal one) if adequate.

Once the information components were defined, they were classified according to the levels of detail required. This classification gives only an overall notion of the levels of detail of the information for boxes of information components, which means that some items contained in each box in may require different levels of detail. However, our intention with this classification is only to show our concern with the matter of the levels of detail without focusing deeply on it.

An example of a step of the CDPD, where information components are associated with the respective levels of detail, is presented in Figure 4.9 (for the UAV as boundary object). The complete set information components and the associated levels of detail, for each boundary object and for each step of the CDPD are presented in the Tables B.5, B.6 and B.7 from Appendix B.4.

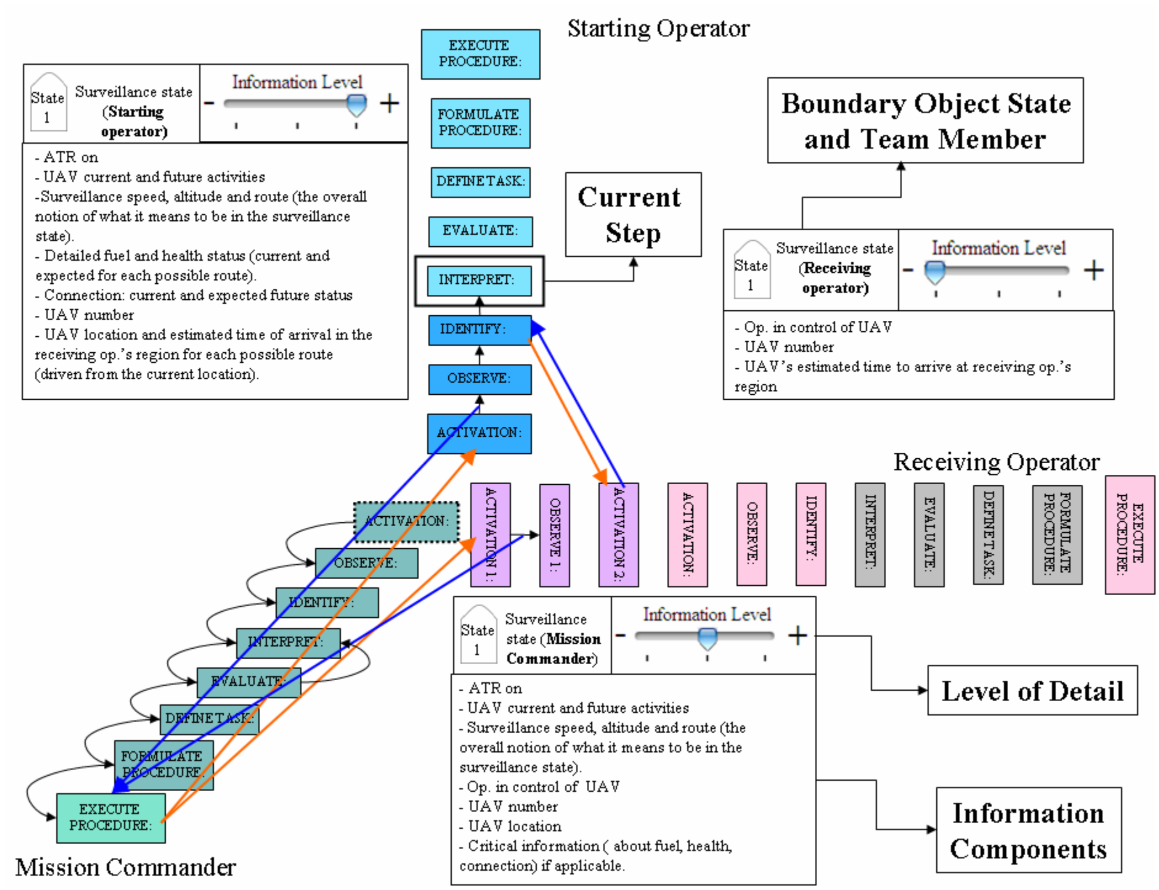


Figure 4.9 – Example of information components and levels of detail for a certain step of the CDPD

4.1.3.5 Identifying Relationships

As can be seen in the Figure 4.9, the amount of required information for each boundary object may be considerably high. Also, when all the information related to each boundary object is put together, it may be confusing to determine their relationships. As an example, one step of the final CDPD (with all the boundary objects put together) is presented. In this example (Table 4-5), the mission commander is in the "identify" step of his/her decision ladder. Due to the various information required for each boundary object, it is difficult to determine the relationships between these pieces of information.

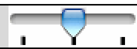
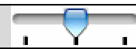
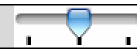
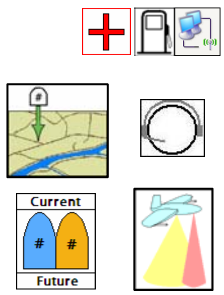
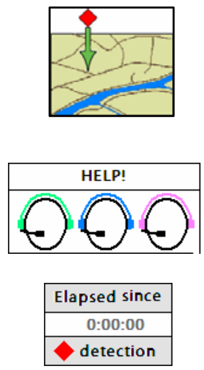
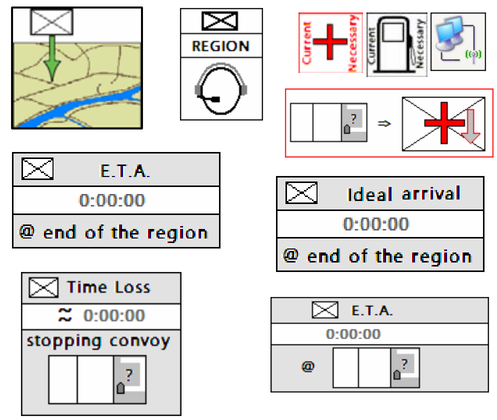
Table 4-5 - Example step of the final CDPD

Mission commander ("IDENTIFY" step)			
Boundary Object	**UAV**	**Target**	**Convoy**
State	Surveillance	Discovered being classified	Stopped/Moving
Info Level	Basic	Basic	Basic
Info Summary	- UAV current and future activities - Overall fuel and health status (only shown if the UAV is expected to reach some critical level in a near future) - Connection status (only shown if it requires attention, if it is critical). - Operator in control of the UAV - UAV number - UAV location - UAV capabilities	- Threat location and the operator responsible for this region - Elapsed time since target was detected - Team members involved in the threat classification	- Current health status and necessary health to get to the end of the team's region - Current fuel status and necessary fuel to get to the end of the team's region - Connection status - Convoy location (in the mission map context) - Convoy location (specific sub-region and correspondent operator) - Estimated time to get to the end of the team's region - Ideal time for convoy to exit the team's region - Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV - Estimated loss of health for crossing the threatened region that should have been surveiled by the shot down UAV - Estimated loss of time for stopping the convoy before entering the threatened region that should have been surveiled by the shot down UAV and waiting for the reassignment

Aiming to simplify the search for relationships, a graphical representation of the information was created. With small icons representing each piece of information, the analyst is capable of searching visually for the relationships instead of reading and having to remember each line of text in association with the other ones. It is important to point out that these icons are not the representation that will be used in the final displays design. This representation is just a draft to help the analyst organize his/her thoughts.

As an example of the adopted approach, the same step from Table 4-5 is presented graphically in Table 4-6.

Table 4-6 - Example step of the final CDPD – Graphical Representation

Mission commander ("IDENTIFY" step)			
Boundary Object	**UAV**	**Target**	**Convoy**
State	Surveillance	Discovered being classified	Stopped/Moving
Info Level			
Info Summary			

The graphical representations are meant to be intuitive, however, for a complete understanding Table 4-7 describes the meaning of each icon.

Table 4-7 - Icons meanings

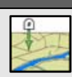
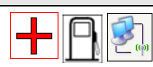
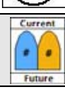
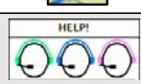
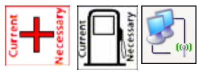
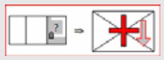
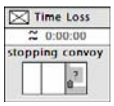
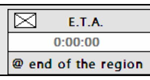
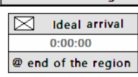
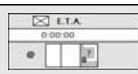
Icon	Meaning
	- UAV location
	- UAV overall fuel, health status and connection
	- UAV capabilities
	- Operator in control of UAV
	- UAV current and future activities - UAV number
	- Threat location
	- Team members involved in the threat classification
	- Elapsed time since target was detected
	- Target ID by receiving operator
	- Convoy location (in the mission map context)
	- Convoy location (specific sub-region and correspondent operator)

Table 4-7 - Icons meanings (cont'd)

Icon	Meaning
	- Convoy current health status and necessary health to get to the end of the team's region - Convoy current fuel status and necessary fuel to get to the end of the team's region - Connection status
	- Convoy estimated loss of health for crossing the threatened region that should have been surveiled by the shot down UAV
	- Estimated loss of time for stopping the convoy before entering the threatened region that should have been surveiled by the shot down UAV and waiting for the reassignment
	- Convoy estimated time to get to the end of the team's region
	- Ideal time for convoy to exit the team's region
	- Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV

Icons like those represented above were created for each piece of information contained in each step of the CDPD. The detailed CDPD with the drawings will not be presented here, since it was only a tool for the relationships search. However, a sample of the relevant relationships found (and the icons associated to the information) is presented below (see Appendix B.5 for a full set of relationships).

Four typed of relationships were detected (where A and B are information components):

I – **A (B)** (dependence) – A depends on B

II – **A & B** (addition) – A and B together may lead to a conclusion

III – **A x B** (tradeoff) – The tradeoff between A and B may lead to a conclusion

IV – **A ➔ B** (consequence) – B is a consequence of A

4.1.4 Summarizing Requirements

Based on the information contained in the boundary objects and on the relationships found between the information components of the boundary objects, a list of requirements was generated and is presented in Tables 4-8 (starting operator) and 4-9 (receiving operator). The table of requirements for the mission commander is presented in the Appendix B.6 (Table B-8) as the current focus is on designing interfaces for the operators.

The requirements for the starting operator's display are divided in two groups: planning the reassignment routes and monitoring the reassignment execution. The display requirements for the receiving operator form a single group, which comprises two activities: planning the handoff time window and monitoring the reassignment route. These requirements divisions represent the changes in the necessary information along the CDPD for each team member.

Table 4-8 – Starting operator display requirements summary

Starting operator	
Planning reassignment routes	Monitoring reassignment execution
TEAM MEMBERS: - Show other team members' available communication options and connectivity status of each option at basic level - Show other team members (involved in the reassignment task) activities at basic level	
CONVOY: - Show convoy position at basic level - Show convoy estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV at basic level	**CONVOY:** - Show convoy position at superficial level
UAV: - Show UAV number - Show UAV location at detailed level - Show ATR status - Show UAV current and future activities at detailed level - Show UAV surveillance speed, altitude and route (the overall notion of what it means to be in the surveillance state) at detailed level - Show critical information (about fuel, health, connection) if applicable at detailed level - Show UAV estimated time of arrival at the receiving operator's region at detailed level (driven from current location only) - Show UAV estimated time to arrive at receiving operator's region (driven from current location and based on chosen route) at detailed level - Show estimated time to enter the range of the target that shot down the UAV at detailed level - Show planned reassignment routes (nominal and safety and which will be the starting one) at basic level	**UAV:** - Show UAV number - Show UAV location at basic level - Show ATR status - Show UAV current and future activities at basic level - Show UAV surveillance speed, altitude and route (the overall notion of what it means to be in the surveillance state) at basic level - Show critical information (about fuel, health, connection) if applicable at basic level - Show UAV estimated time to arrive at receiving operator's region (driven from current location and based on chosen route) at basic level - Show estimated time to enter the range of the target that shot down the UAV at basic level - Show planned reassignment routes (nominal and safety and which will be the starting one) at basic level - Show planned reassignment routes and which route is the current one at basic level - Show activity: UAV transitioning from surveillance/transiting route to transiting/surveillance route at basic level - Show activity: UAV following the reassignment route ("on route") at basic level - Show UAV is going from low/high to high/low altitude (possibility to monitor altitude) at basic level - Show UAV is going from low/high to high/low speed (possibility to monitor speed) at basic level - Show UAV context info: handoff time window being planned by receiving op (and expected time of planning completion) at superficial level - Show estimated time for change in control of the UAV at basic level - Show UAV context info: reassignment execution being monitored by receiving operator (and expected time of completion) - Show UAV context info: receiving op preparing to take control of the UAV (and expected time of handoff)

Table 4-8 – Starting operator display requirements summary (cont.)

<table>
<tr><th colspan="2">Starting operator</th></tr>
<tr><th>Planning reassignment routes</th><th>Monitoring reassignment execution</th></tr>
<tr><td>TARGET:
- Target location at basic level
- Weapons range (aerial) at basic level
- Estimated time for the target to be destroyed (based on current and near future strike team schedule) at basic level
- Scheduled time for the target to be destroyed at basic level</td><td>TARGET:
- Target location at superficial level
- Weapons range (aerial) at superficial level
- Estimated time for the target to be destroyed (based on current and near future strike team schedule) at superficial level
- Scheduled time for the target to be destroyed at superficial level
- Destroyed target location at superficial level</td></tr>
<tr><td>RELATIONSHIPS:
-Show [<u>ATR on</u>], [<u>low speed</u>], [<u>low altitude</u>], [<u>surveillance route</u>] and [<u>UAV activities</u>] and their consequence relationship.
- Show [UAV location], [target location], [estimated target range] and [estimated time for the UAV to enter the target’s range] and their dependency relationship.
- Show [UAV estimated time to arrive at the receiving operator’s region] and [UAV location] and their dependency relationship
- Show [estimated time to arrive at the receiving op’s region] and [current and necessary fuel and health] tradeoff relationship
- Show [estimated time for the UAV to enter the target’s range] and [estimated time for the target to be destroyed] and their addition relationship
- Show [estimated time for the UAV to arrive at the receiving operator’s region] and [estimated time for the convoy to arrive at the threatened area that should have been surveiled by the shot down UAV] and their addition relationship
- Show current and necessary [<u>health</u>] and [<u>fuel</u>] and their addition relationship
- Show [current and expected receiving op’s. activities] and [estimated time for the UAV to arrive at the receiving operator’s region] and their addition relationship</td><td>RELATIONSHIPS:
-Show [<u>ATR on</u>], [<u>low speed</u>], [<u>low altitude</u>], [<u>surveillance route</u>] and [<u>UAV activities</u>] and their consequence relationship.
- Show [UAV location], [target location], [estimated target range] and [estimated time for the UAV to enter the target’s range] and their dependency relationship.
- Show [estimated time for the UAV to enter the target’s range] and [estimated time for the target to be destroyed] and their addition relationship
- Show [current and expected receiving op’s. activities] and [estimated time for the UAV to arrive at the receiving operator’s region] and their addition relationship
- Show [estimated time for the UAV to enter the receiving operator’s region] and [planned route] and their dependency relationship
- Show [estimated time for the UAV to enter the range of the target that shot down the UAV] and [planned route] and their dependency relationship
- Show [<u>route change</u>], [<u>altitude change</u>] and [<u>speed change</u>] and [<u>ATR off</u>] and their addition relationship
- Show [(a)] and [<u>UAV route: safety or nominal</u>] and their consequence relationship where:
(a) The [estimated time for the UAV to enter the target’s range] and [the scheduled time for the target to be destroyed] (addition relationship)
- Show [<u>target state: destroyed</u>] and [<u>UAV route: safety or nominal</u>] and their consequence relationship</td></tr>
</table>

Table 4-9 – Receiving operator display requirements summary

Receiving operator
Planning Handoff Time Window/Monitoring Reassignment Route
TEAM MEMBERS: - Show other team members' available communication options and connectivity status of each option at basic level - Show other team members(involved in the reassignment task) activities at basic level
CONVOY - Show convoy position at basic level - Show convoy estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV at basic level
UAV - Show operator in control of UAV - Show UAV number - Show UAV's estimated time to arrive at receiving operator's region at basic level - Show UAV location at basic level - Show any critical/off nominal info at basic level - Show UAV location and estimated time to arrive at receiving operator's region (driven from current location and based on chosen route) at basic level - Show estimated time to enter the range of the target that shot down the UAV at basic level - Show planned reassignment routes (nominal and safety and which will be the starting one) at basic level - Show planned reassignment routes and which route is the current one at basic level - Show activity: UAV transitioning from surveillance/transiting route to transiting/surveillance route at basic level - Show activity: UAV following the reassignment route ("on route") at basic level - Show UAV is going from low/high to high/low altitude (possibility to monitor altitude) at basic level - Show UAV is going from low/high to high/low speed (possibility to monitor speed) at basic level - Show estimated time for change in control of the UAV at basic level - Show ATR status - Show UAV context info: reassignment execution being monitored by starting operator (and expected time of completion) - Show UAV context info: starting operator preparing to surrender the UAV control
TARGET - Show info about the unclassified target (intell, imagery, etc) at detailed level (if still being classified) - Show weapons range (aerial) at basic level - Show target location at basic level - Show target activity level (aerial) at basic level - Show estimated time for the target to be destroyed (based on current and near future strike team schedule) at basic level - Show scheduled time for the target to be destroyed at basic level - Show destroyed target location at superficial level
RELATIONSHIPS: - Show [target position], [target range], [scheduled time for the target to be destroyed], and [target level of activity] and their addition relationship - Show [estimated time for the convoy to enter the threatened region] and [estimated time for the UAV to enter the receiving op's region] and their addition relationship - Show [estimated time for the UAV to enter the receiving operator's region] and [planned route] and their dependency relationship - Show [estimated time for the UAV to enter the range of the target that shot down the UAV] and [planned route] and their dependency relationship - Show [route change], [altitude change] and [speed change] and [ATR off] and their addition relationship - Show [(a)] and [UAV route: safety or nominal] and their consequence relationship where: (a) The [estimated time for the UAV to enter the target's range] and [the scheduled time for the target to be destroyed] (addition relationship) - Show [target state: destroyed] and [UAV route: safety or nominal] and their consequence relationship

Chapter 5 Re-Designing Displays Based on the Hybrid CTA Collaborative Extension

This chapter presents the re-design of a set of UAV operator displays originally designed using the Hybrid CTA method. The new designs will be based on the requirements obtained in Chapter 4. The existing operators' displays (obtained through the Hybrid CTA), are first presented, followed by the re-designed displays (based on the method proposed in this report).

Since the focus of the requirements generation from Chapter 4 was on the reassignment task, the display to be presented in detail will be reroute/reassign displays. It is acknowledged that the requirements obtained in Chapter 4 will have some influence on the other displays; however, they will only be presented superficially.

5.1 Displays Obtained Based on the Original Hybrid CTA

Based on the list of requirements derived from task analysis performed using the original Hybrid CTA method, a three screen display design was created. This section presents these displays and their basic functionality.

The three screens consist of:

- The Map Display (Figure 5.1) in which the general geospatial and temporal information of the mission is presented,
- The Communication Display (Figure 5.2) in which the main focus is the interaction between different operators and between operators and the mission commander, and
- The Task Display (Figure 5.3 and Figure 5.4) in which operators are able to reroute and reassign UAVs, as well as identify targets.

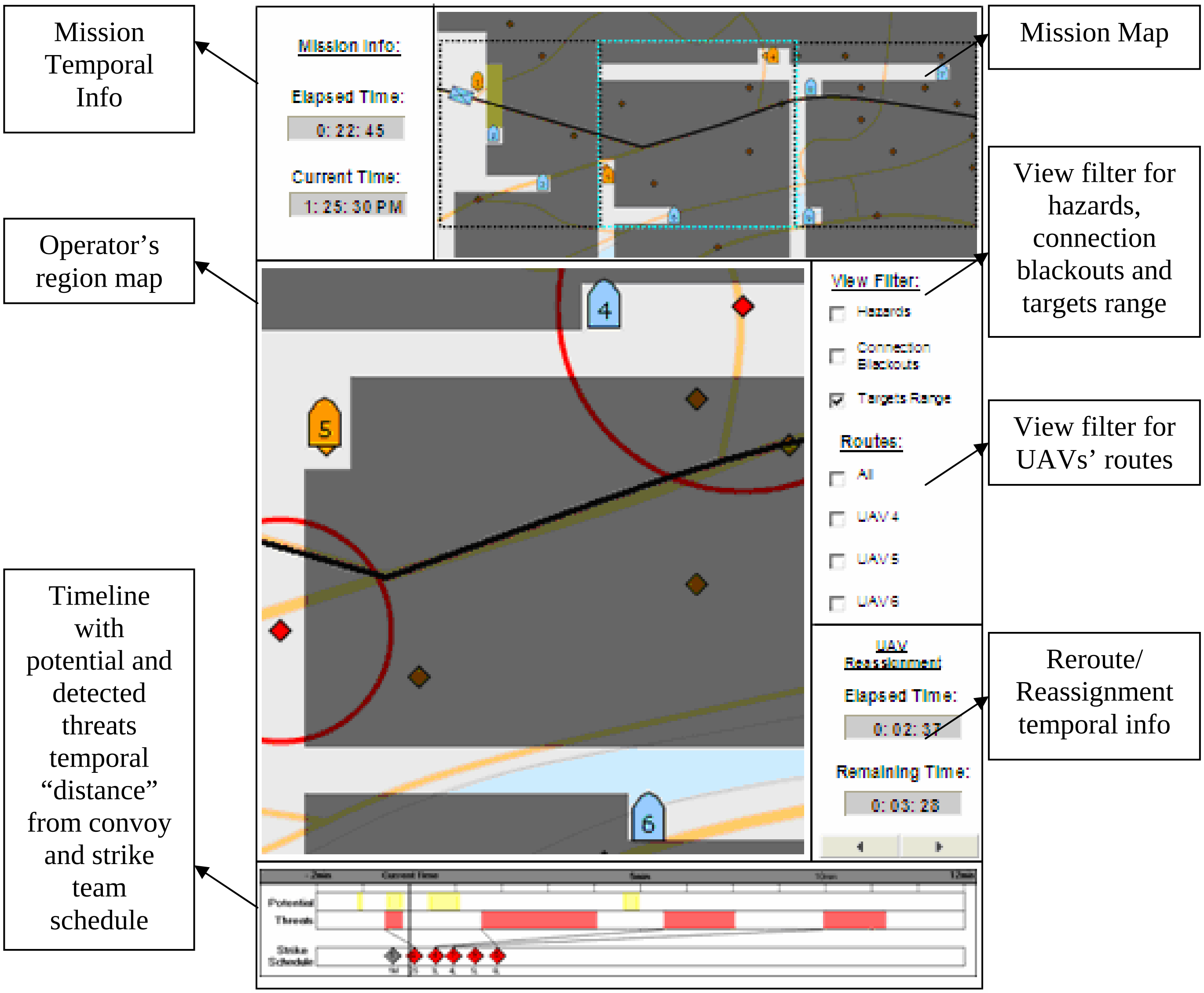


Figure 5.1 - Map Display

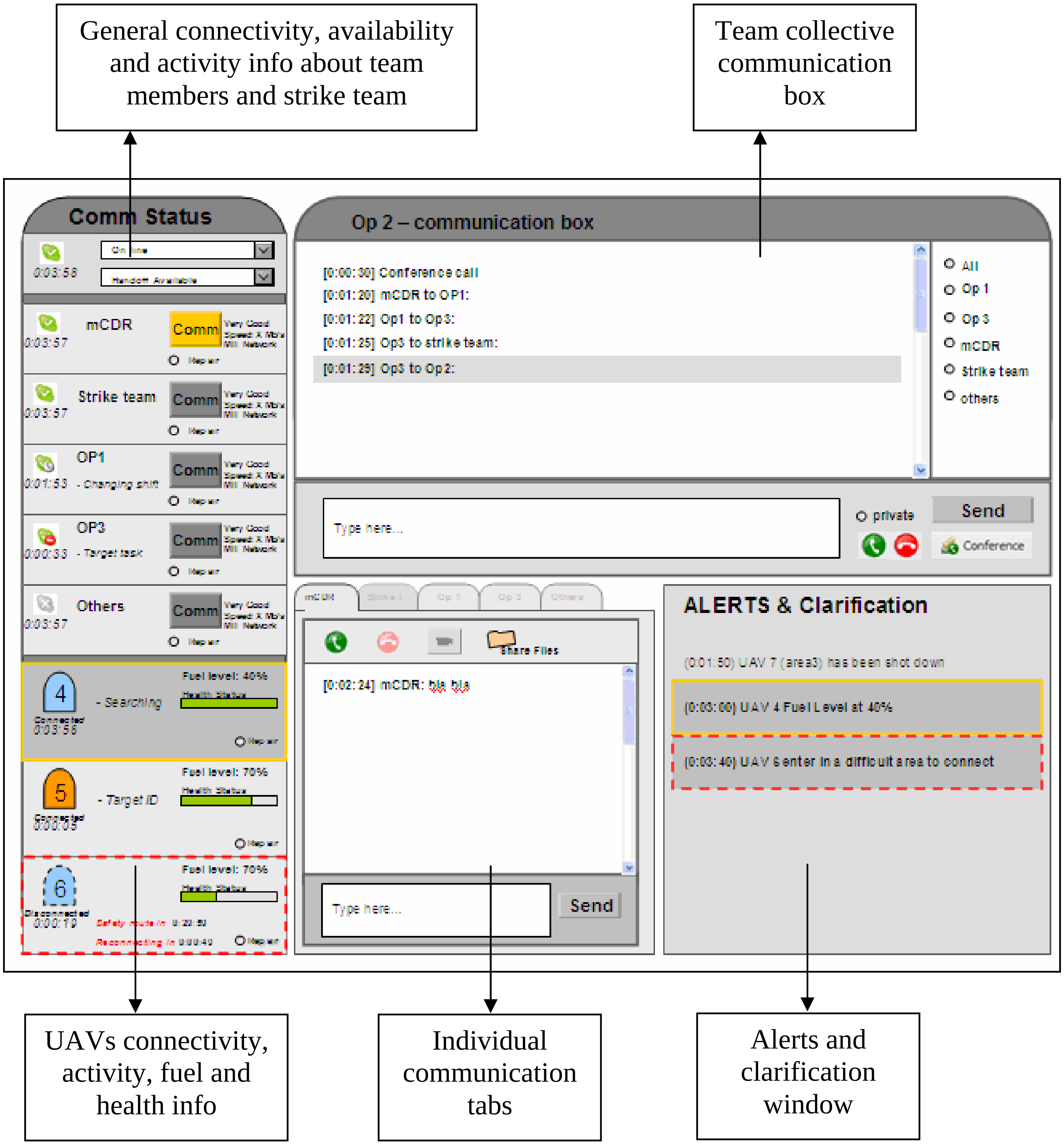


Figure 5.2 - Communication Display

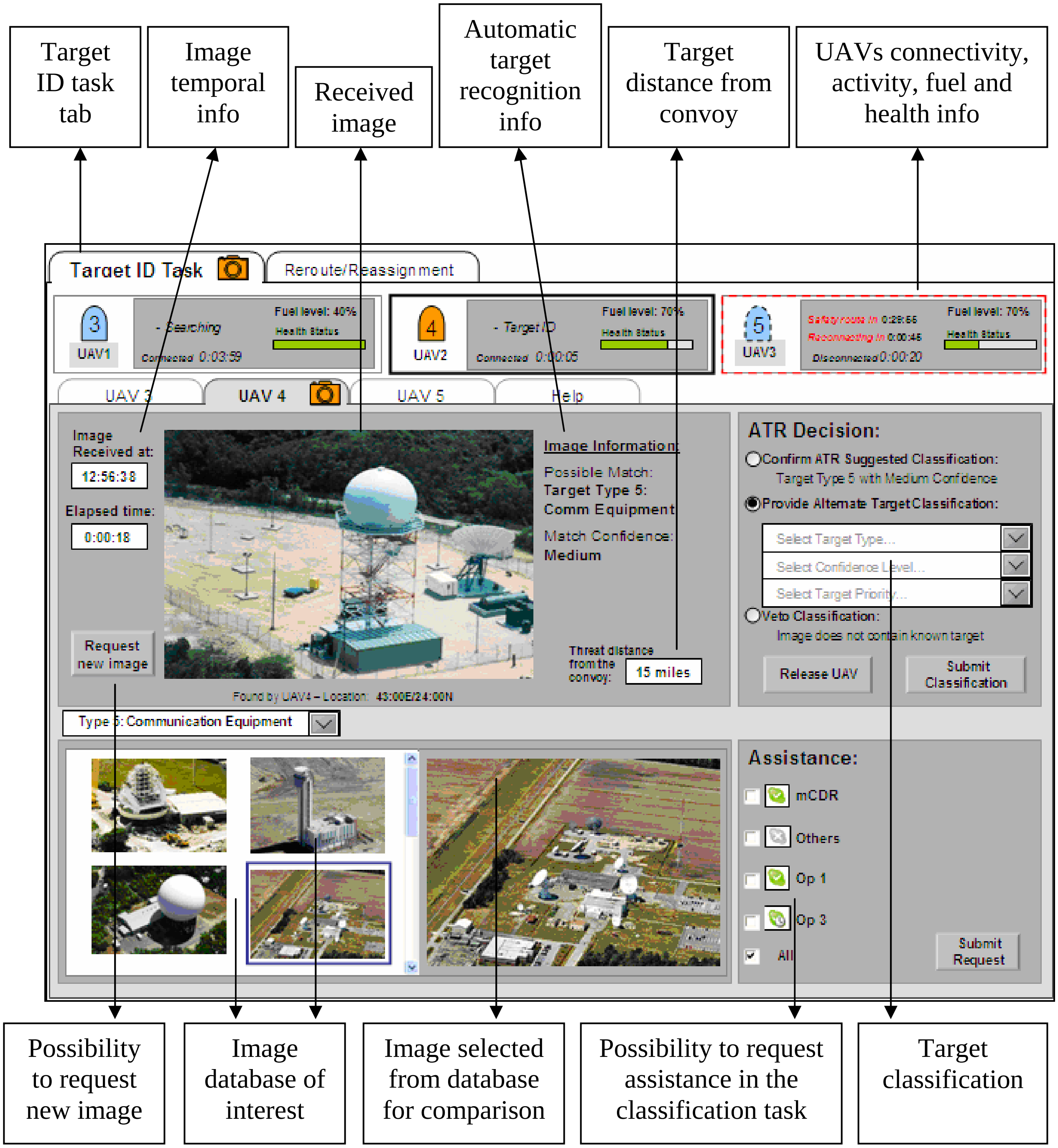


Figure 5.3 – Task Display: Target ID Screen

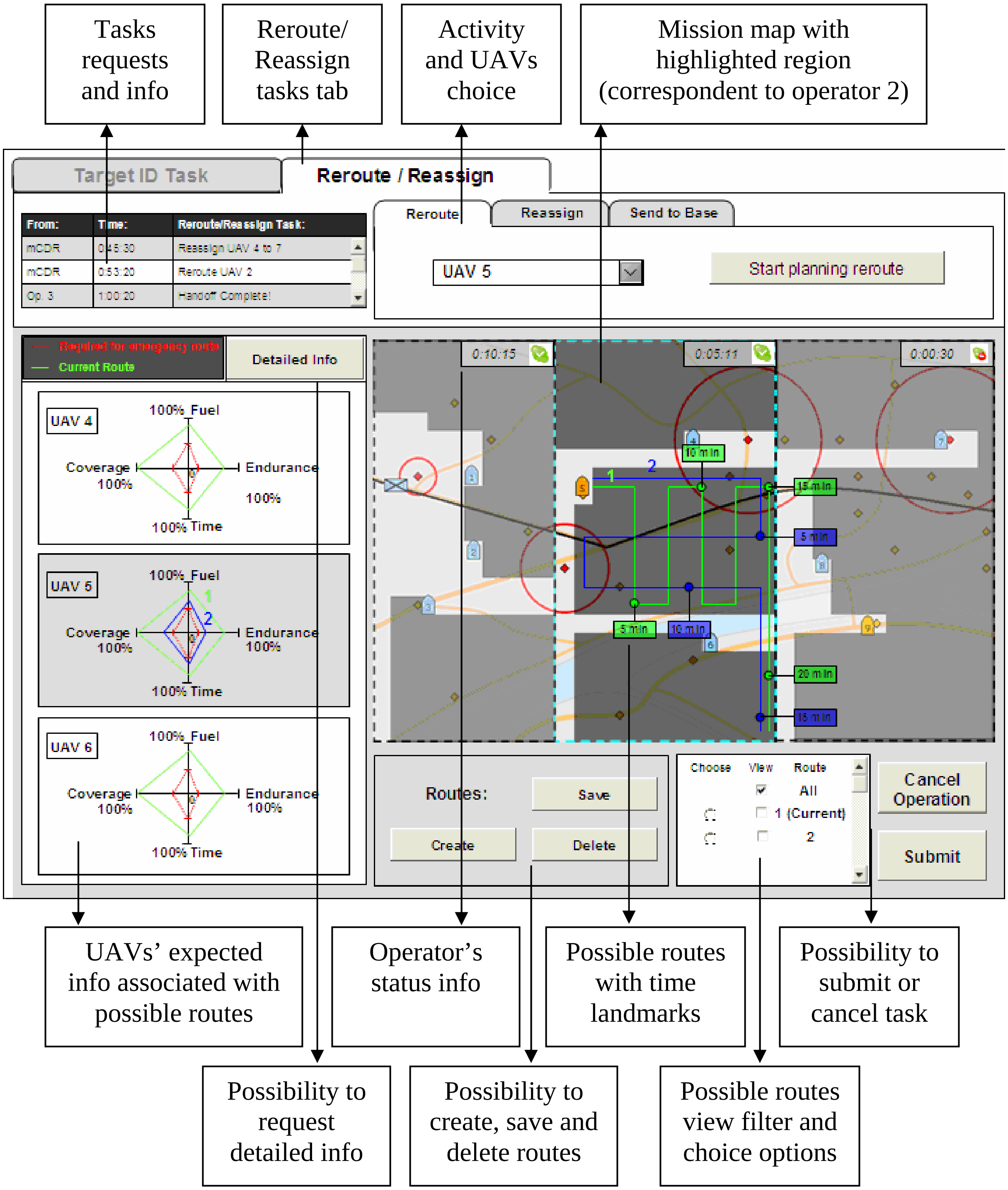


Figure 5.4 – Task Display: Reroute/Reassign Screen

5.2 Displays Based on the Hybrid CTA Collaborative Extension

This section presents the displays obtained based on the requirements generated from the Hybrid CTA Collaborative Extension. Since the operators' informational needs change as the task progresses, for each operator, the display should accommodate these changes. For this reason, the displays are presented based on the chronological order imposed by the CDPD. If a display has not changed between two or more steps of the CDPD, its representation will be omitted, that is, we will only present a display when it changes.

5.2.1 CDPD – From step 1 to step 7

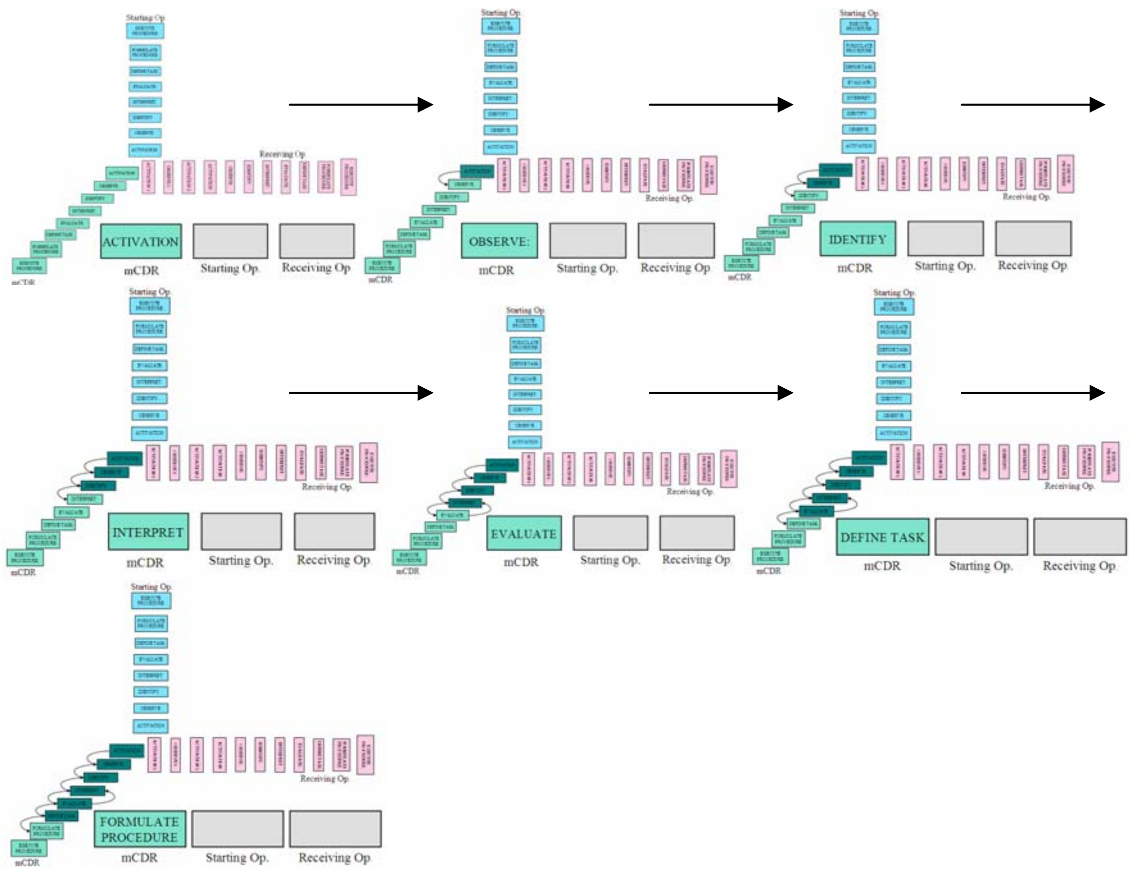


Figure 5.5 – CDPD – From step 1 to step 7

These steps are prior to the operators' activation for the reassignment. For this reason, both operators will be working on tasks that are not related to the reassignment. The map display, the communication display and the target ID display will look almost exactly like presented in Figures 5.1 to 5.3.

One of the differences between the old and the new displays is related to the UAVs representation. This change was due to a change in the US military display standards. This standard states that a "friend" UAV must always be represented in blue, unless it has been shot down. Table 5-1 describes the representation change:

Table 5-1 – UAV representation change

Representation Meaning:	Old representation:	New representation:
The UAV is surveilling the region		
The UAV is flying over a possible threat (acquiring the imagery that will be used to identify it)		
The UAV has been shot down		

Another difference appears in the communication display. According to the requirements generated by the Hybrid CTA Collaborative Extension method, the operators need to know, during the whole mission, the number of pending tasks the other operators will have to execute (and they can see what the tasks are by clicking the pending tasks box).

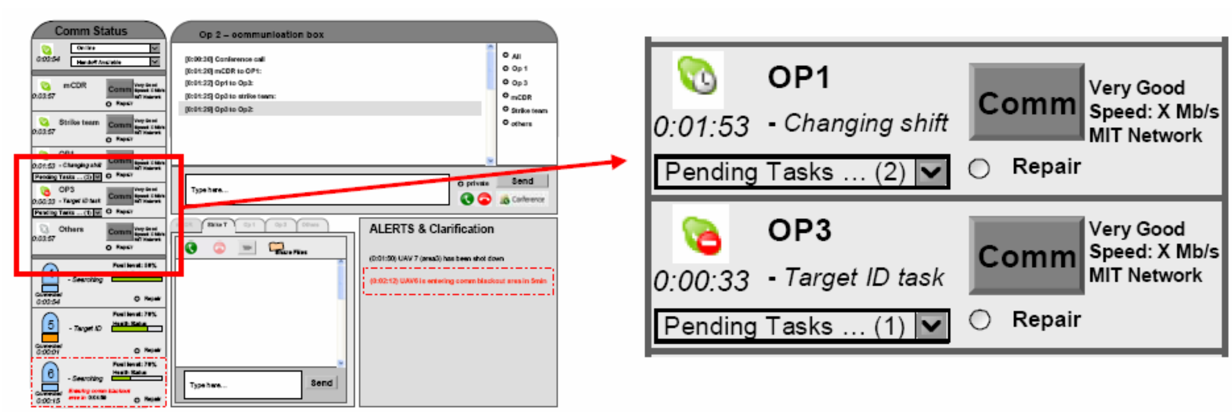


Figure 5.6 – Communication display – Pending Taks

The major changes appear in the reroute/reassign display. First, the display's name was changed to re-planning. Figure 5.7 shows how an operator would see the re-planning display prior to the activation sent by the mission commander (of course, the highlighted area on the map would be changed if the operator was not operator 2).

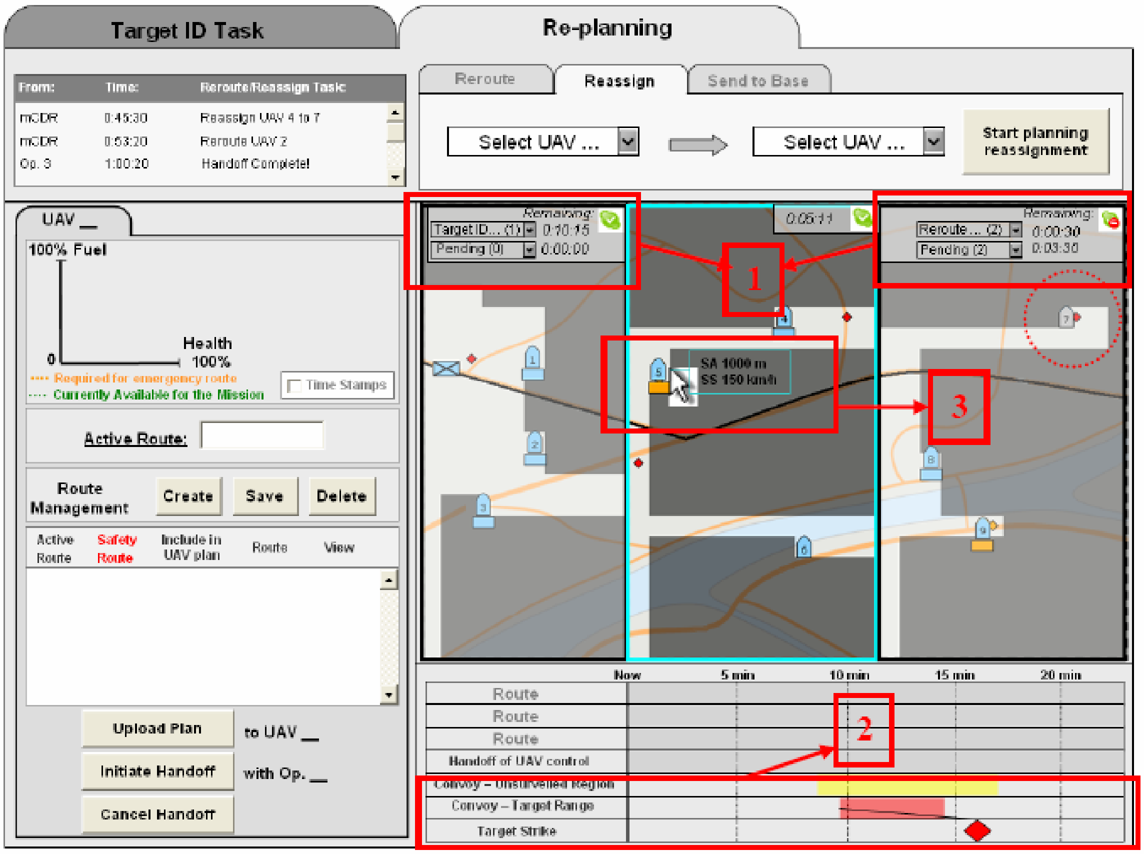


Figure 5.7 – Re-planning display

The display's complete functionality will be explained as we go through the CDPD steps, however, there are some features that can be explained at this point.

1)

Figure 5.8 – Operators' current and pending activities

New requirements indicate that each operator should be aware of the number of the current and the future activities of the other operators, what their current task is, how long it will take for them to complete their current and future tasks and their status.

This feature (detailed in Figure 5.8) helps the reassignment task since it gives the operators a real notion of when to execute the task and interact providing the least disturbance to the other operators' current activities. Besides, the operator does not have to look to another display to acquire this information.

2)

Figure 5.9 – Temporal information about the possible threats to the convoy

This timeline is another innovation derived from the requirements identified by the Hybrid CTA Collaborative Extension method. It gives the operator temporal information about the convoy (when it will enter an unsurveilled region and when it will enter a known target range) and about the target strike schedule. Using this information (Figure 5.9), the operator may be able to plan routes and make decisions using almost exclusively in the re-planning display. This reduces the distraction and possible confusion of having to look at the map display while planning reassignments. It also gives an instant notion of how fast the plans will have to be made in order to keep the convoy safe.

3)

Figure 5.10 – UAV altitude and speed

At any time, the operator can pass the mouse over one of the UAVs under his/her control and obtain information such as the SA (surveillance altitude) and the SS (surveillance speed) as illustrated in Figure 5.10.

5.2.2 CDPD – Step 8

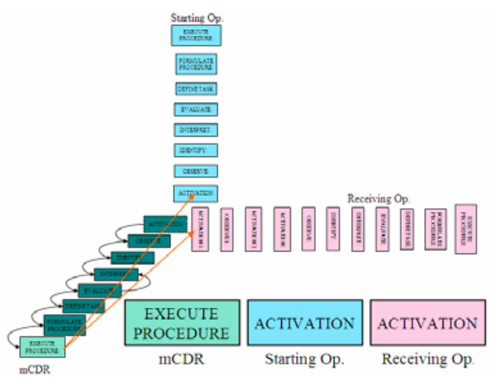


Figure 5.11 – CDPD – Step 8

At this point, both the receiving and the starting operators receive the activation from the mission commander to start preparing to plan and execute the reassignment. The message from the mission commander is presented at the communication display. The starting operator's re-planning tab at the task display starts to blink in black and orange. Also, the UAV that is supposed to be reassigned also blinks on every display (map, communication and task displays) to help the operator avoid mistakes when picking the UAV to reassign and to increase the likelihood that the operator will perceive and not forget the reassignment task.

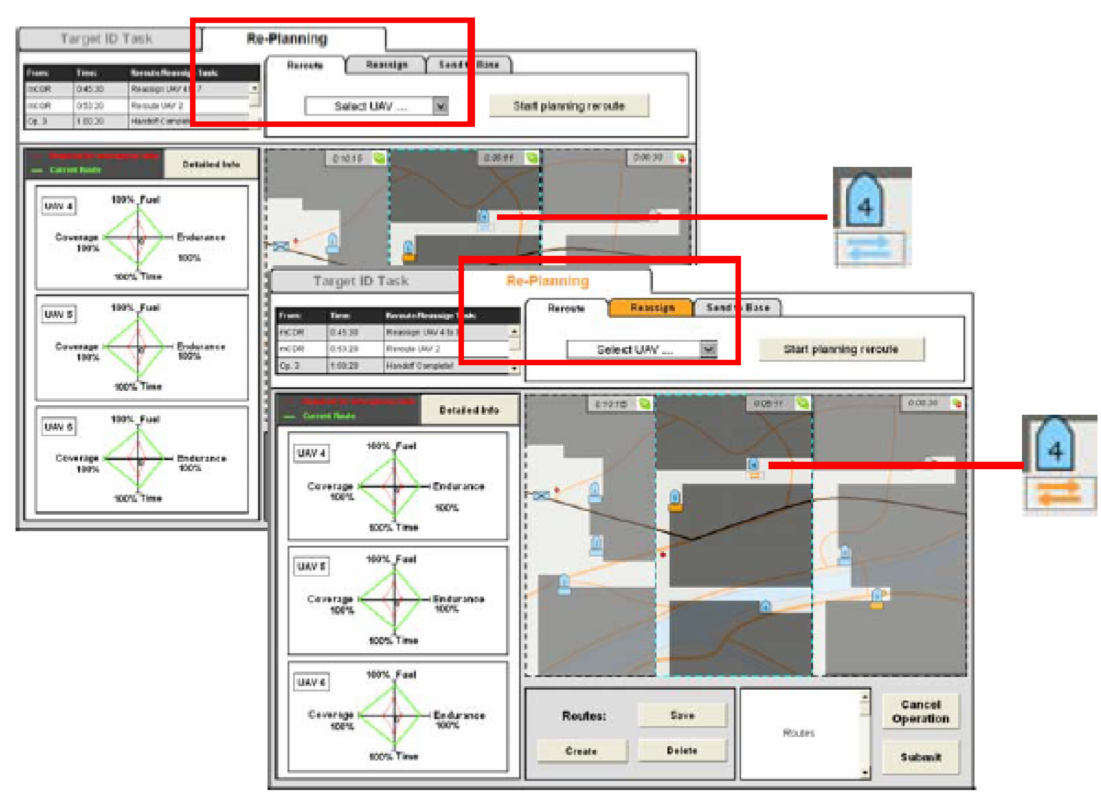


Figure 5.12 - Task display right after the mission commander activation

5.2.3 CDPD – From step 9 to step 15

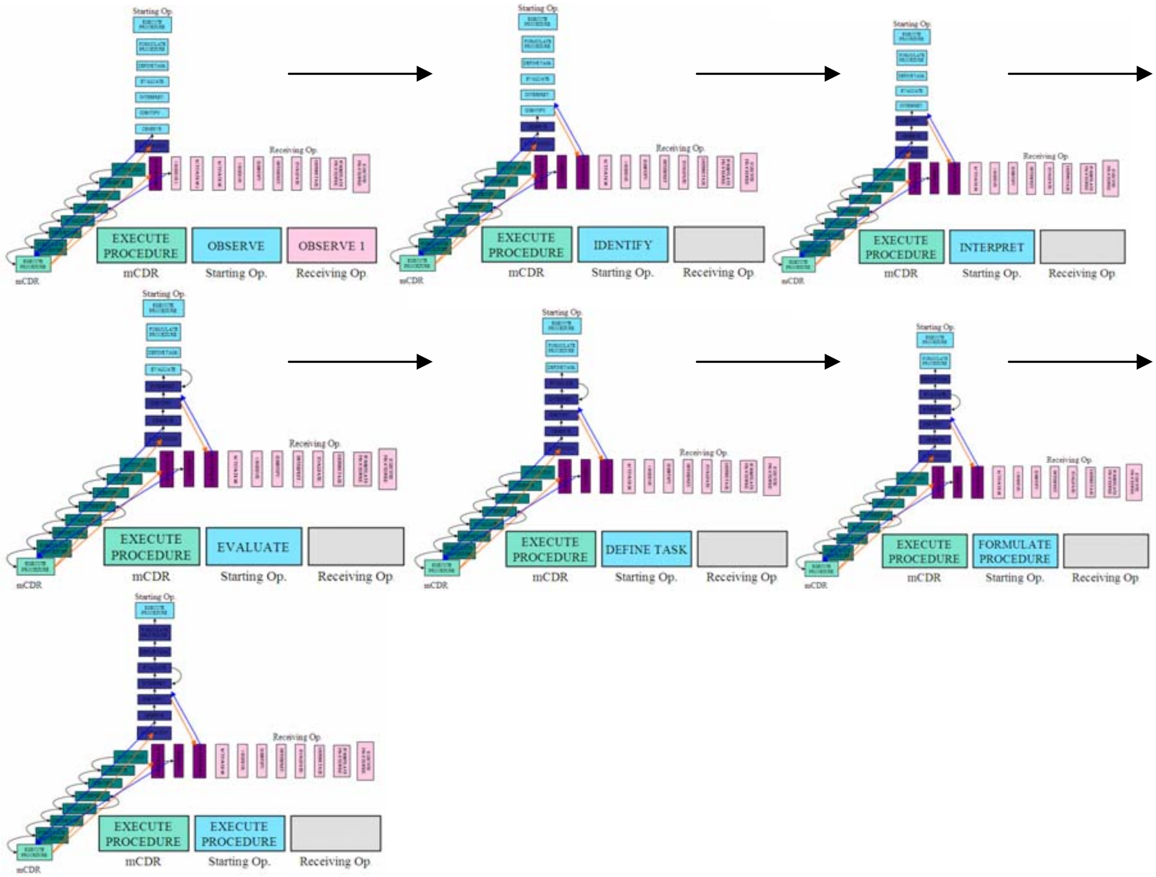


Figure 5.13 – CDPD – From step 9 to step 15

These are the steps in which the starting operator plans the reassignment. He/She starts the plan by defining which UAVs are involved in the reassignment task.

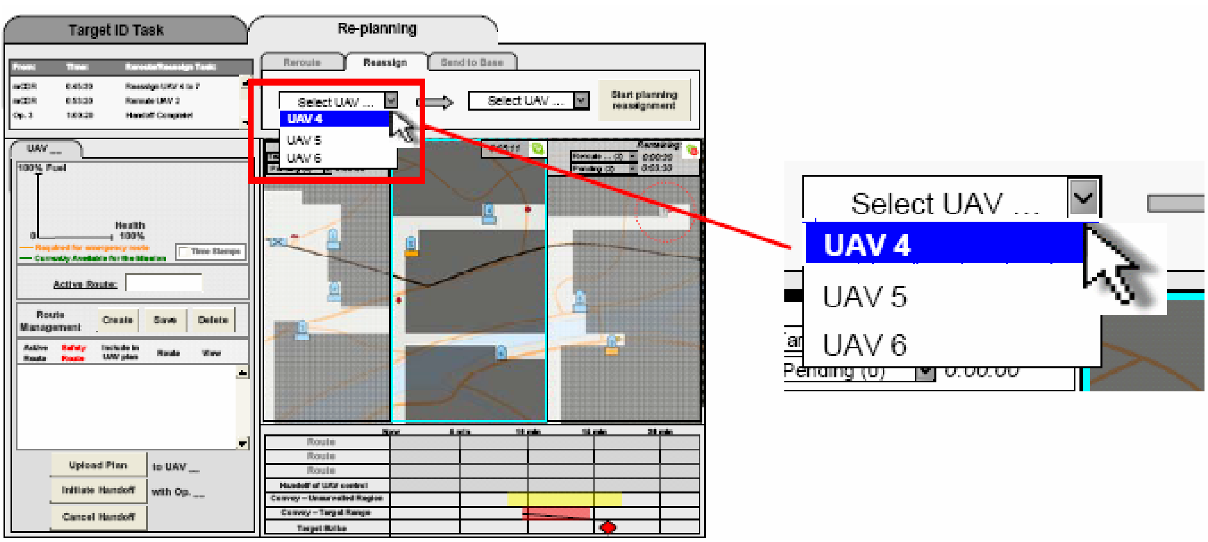


Figure 5.14 - Starting operator selects the UAV to be reassingned

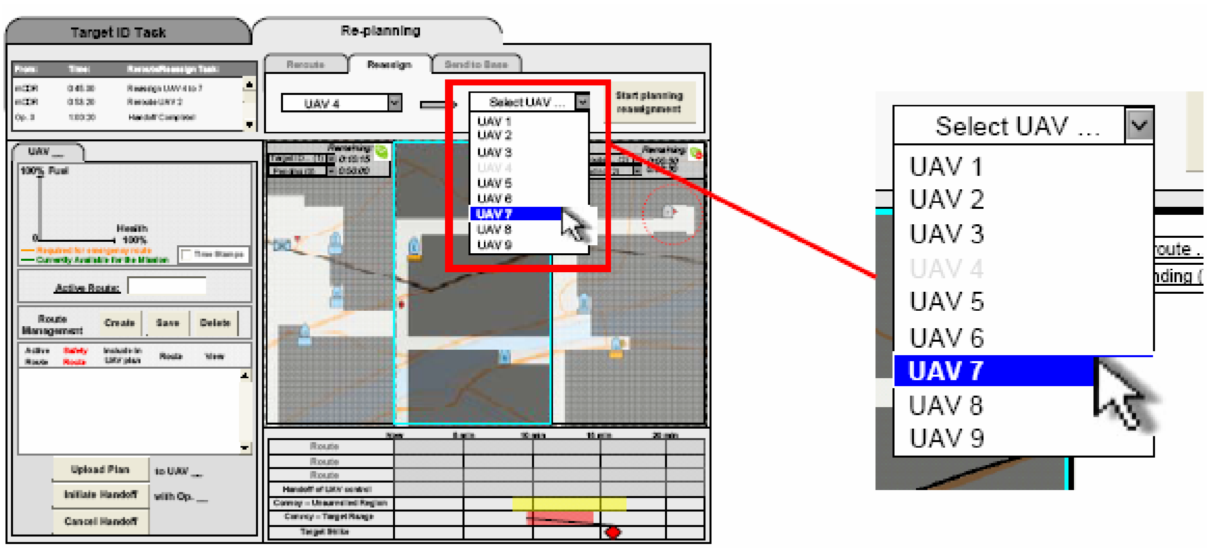


Figure 5.15 – Starting operator selects the shot down UAV (or the UAV to be substituted by the reassigned UAV)

Once the UAVs are selected, the starting operator starts planning the reassignment. It is important to notice that the starting operator is aware of the current and future activities the receiving operator may be involved in. Thus, the starting operator may need to use the communication display to coordinate with and/or send a notice to the receiving operator informing he/she is about to start the reassignment planning.

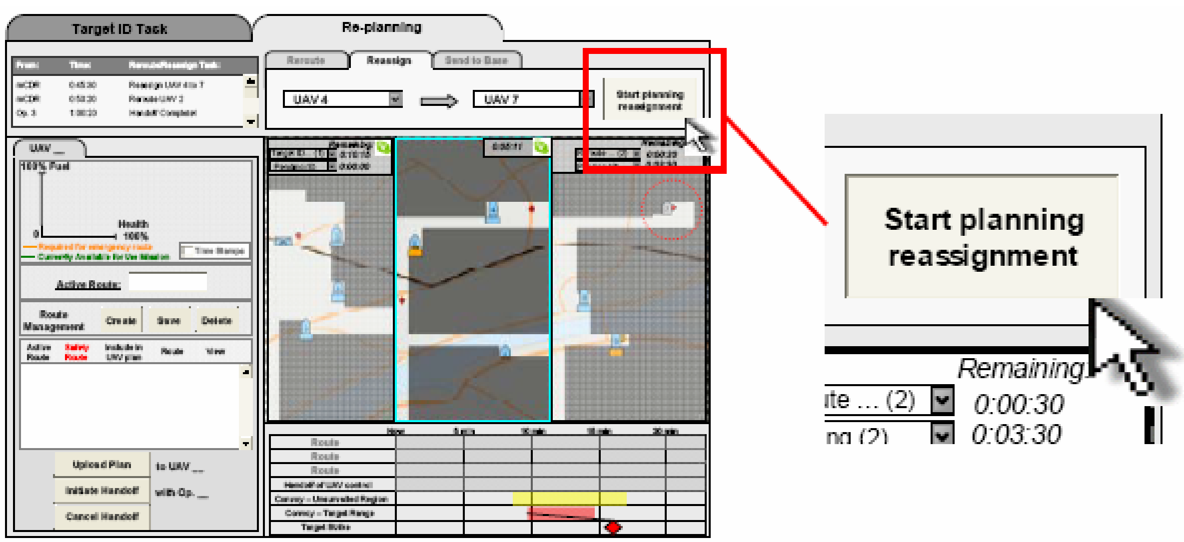


Figure 5.16 – Starting operator starts planning the reassignment

Once the starting operator clicks the “start planning reassignment” button, he/she receives information about the current route in which the UAV to be reassigned is, about the default reassignment route (a straight line between the involved UAVs) and about the UAV (fuel and health). The information is explained in the following paragraphs.

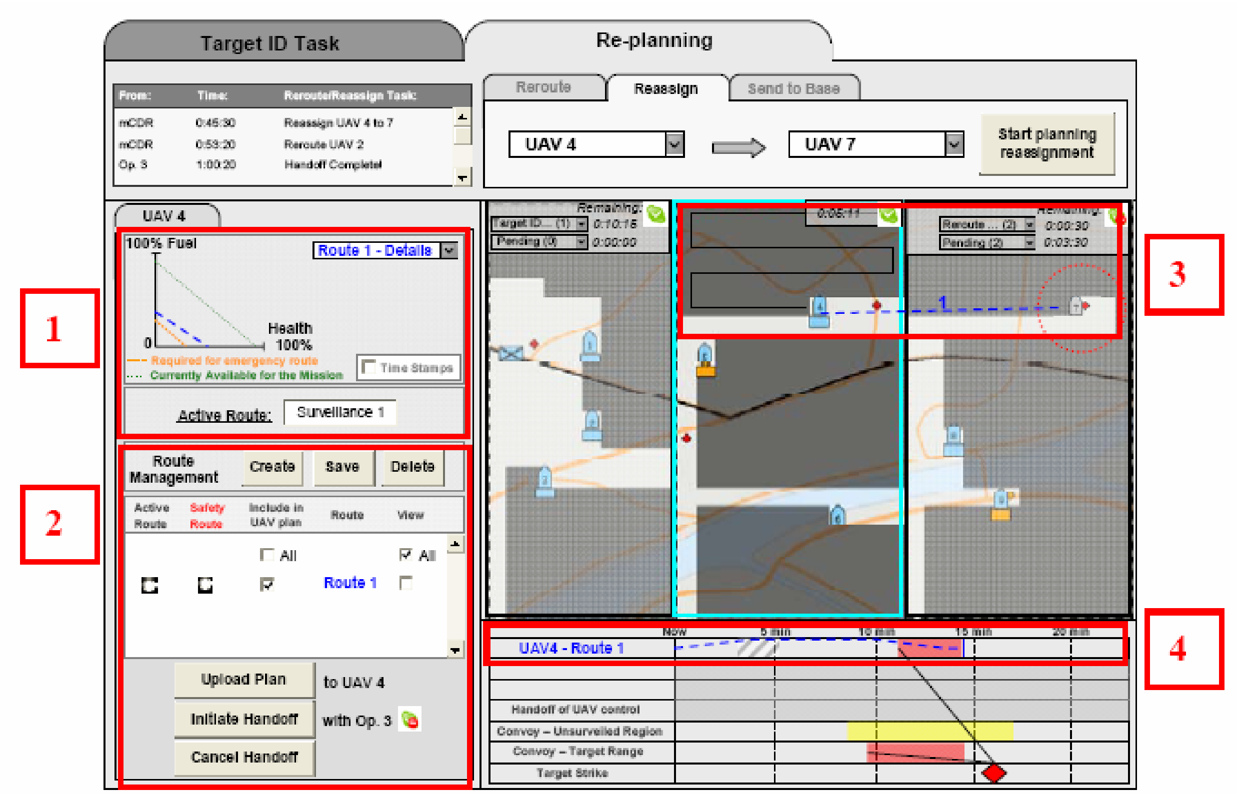


Figure 5.17 – Starting operator reassignment display

1)

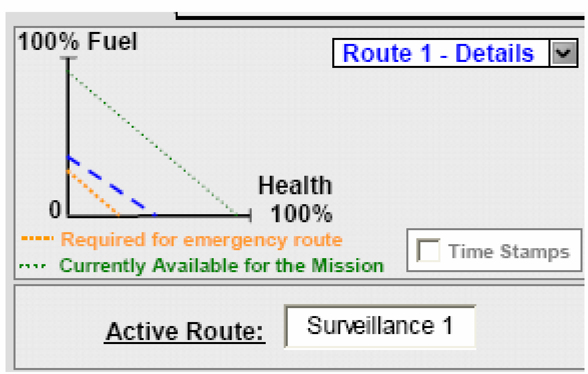


Figure 5.18 – UAV fuel and health

The graph presents a qualitative relationship between UAV fuel and health and allows a comparison between the minimum required (required for the emergency route) the available fuel and health to finish the mission and the necessary fuel and health to conclude a certain route (in this case, route 1). At the upper right corner, details about the route can be obtained. At the bottom, the starting operator sees the current route the UAV is in (this information can be used to avoid confusion – the starting operator could be in doubt, at a certain point, if he had already sent a new route to the UAV).

2)

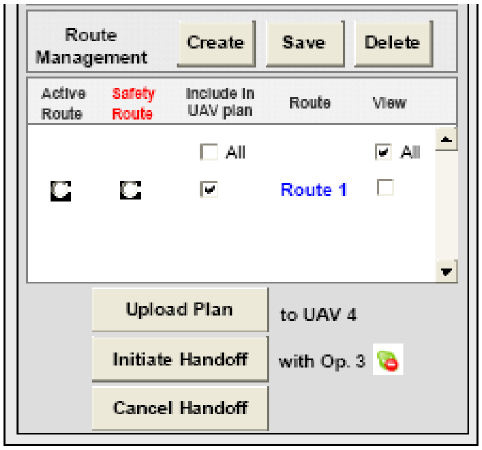


Figure 5.19 – Route management feature

Figure 5.19 presents the route management feature. Using this part of the display the starting operator can create, save and delete new routes, can define the active route and the safety route, can choose the routes to be included in the plan to be sent to the UAV and can choose the routes to be seen in the map at the right. The active route is the route the UAV will be following once the handoff starts and the safety route may be any route that does not pass by any target ranges.

Once the operator defines his choices in the route management box, he uploads the plan to the UAV. However, it is only after confirming the handoff initiation that the UAV will start to obey the plans.

At the bottom, the starting operator can see which UAV is reassigned and who the corresponding receiving operator is (as well as his/her status).

3)

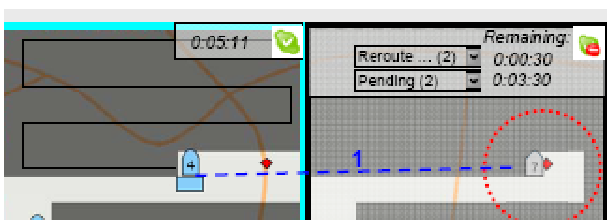


Figure 5.20 – Routes displayed on the map

The current and planned routes may be displayed on the map (Figure 5.20).

4)

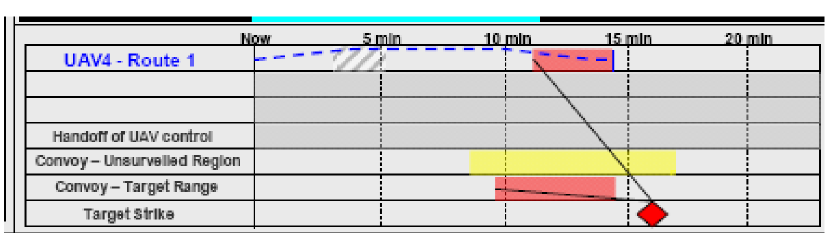


Figure 5.21 - Timeline

The temporal details of the planned route are presented in a timeline (Figure 5.21). The first line shows Route 1 and relates its duration and altitude to the time windows in which the UAV will pass by connection blackouts (dashed in gray regions) and by target ranges (red regions). Also, the starting operator is able to compare, using the timeline, each planned route duration and the "distance" (in time) from the convoy to the target that shot down the UAV (as well as the target strike schedule).

Another feature that can be used to help the starting operator to compare different route plans is the "time stamps" located along the UAV route on the map (Figure 5.22). The time stamps give a better notion of the gradual UAV change in position along a certain route.

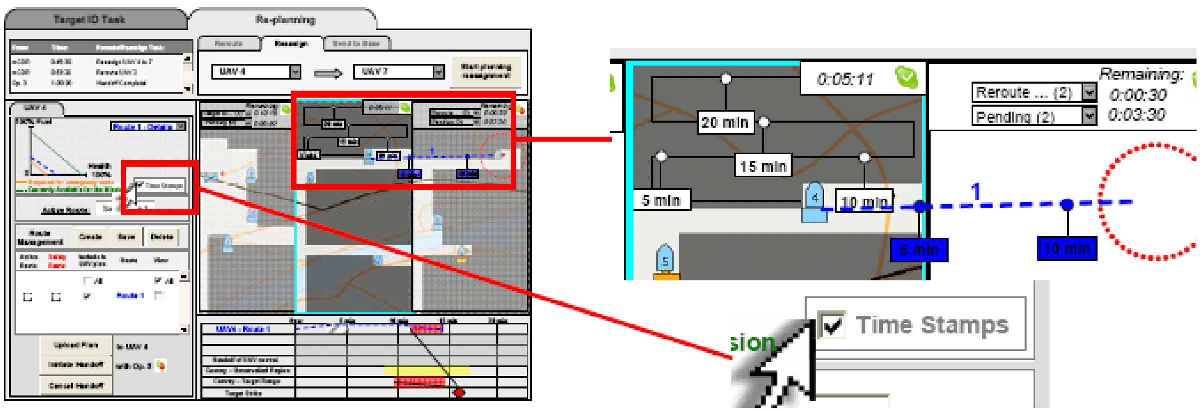


Figure 5.22 - Time Stamps

At this point, the starting operator can create new routes. To create a new route, the operator has to click the "create" button.

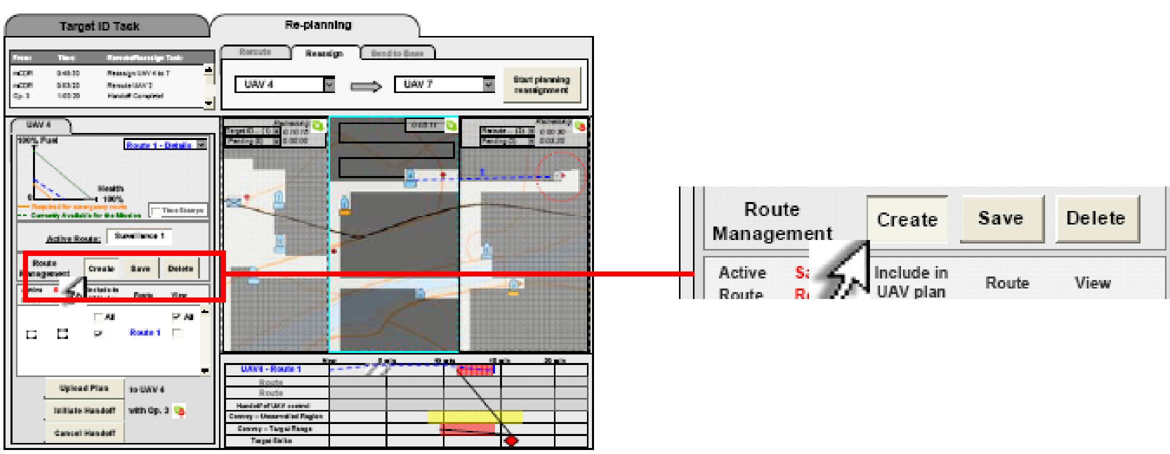


Figure 5.23 - Creating a new route

Once the "create" button is clicked (Figure 5.23), regions where there may be possible connection blackouts are shown. The route that was being followed by the shot down UAV is also displayed. The operator creates the new route by clicking on certain points where he/she wants the UAV to go and straight lines are automatically built between the points (Figure 5.24).

Figure 5.24 – Creating the new route - step by step

Once the operator has finished drawing the route, he/she can save or delete it (Figure 5.25).

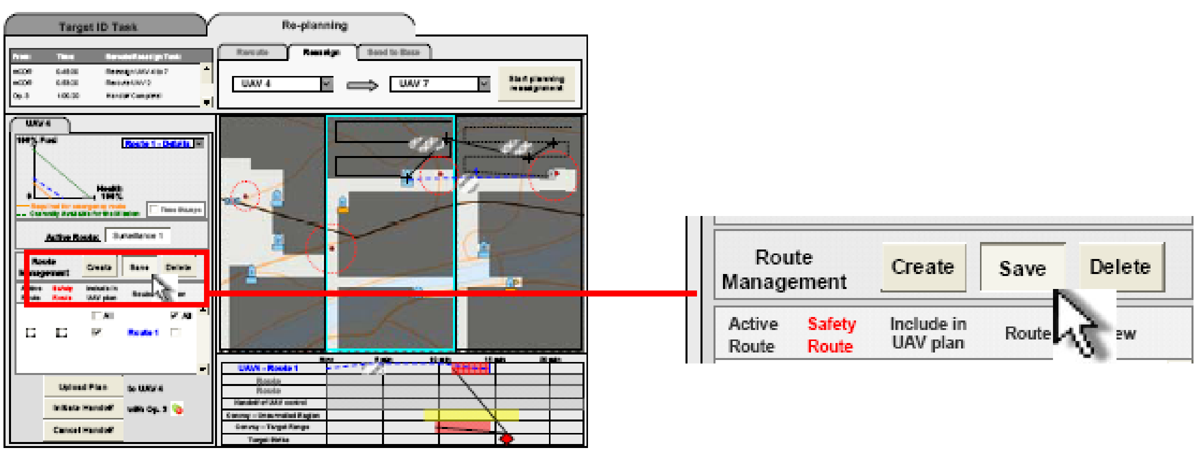


Figure 5.25 – Saving a new route

Once the new route is saved, it is shown using the same features that were explained for the Route 1 (Figure 5.26).

Figure 5.26 – Route 2 (Light Green)

As can be seen in the timeline in Figure 5.26, the Route 2 does not pass with range of any known targets, thus, it is a potential safety route. If the operator decides to make it the safety route, he/she simply defines it as so in the route management box (Figure 5.27).

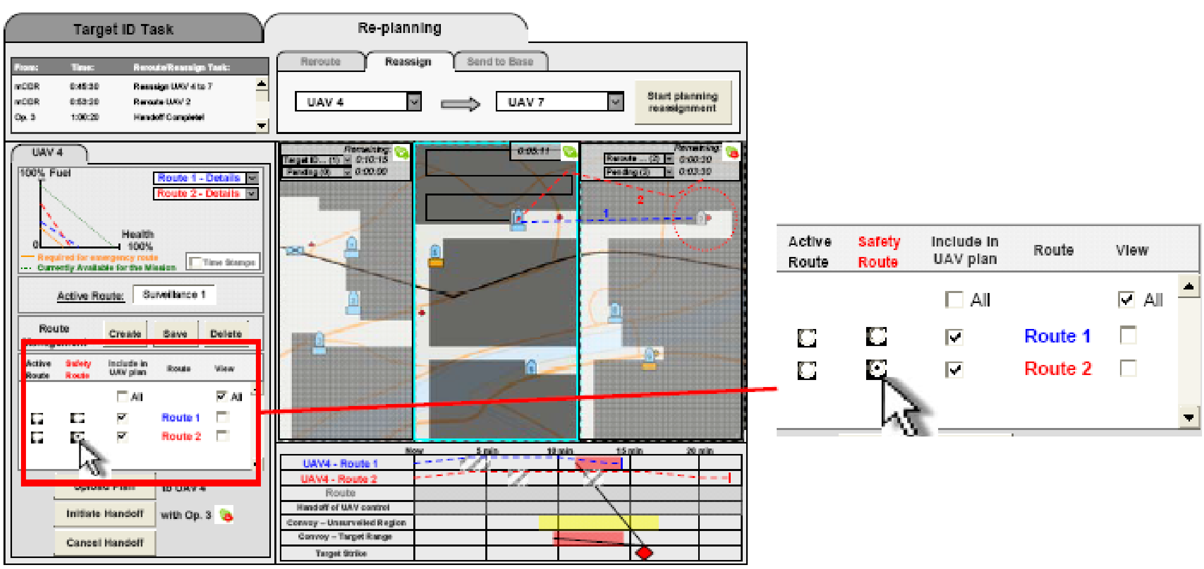


Figure 5.27 – Defining the safety route

The starting operator may create a third route. The process of creating a Route 3 is exactly analogous to creating Route 2. Figure 5.28 shows the display with the three routes. At this point the operator defines the active route for the reassignment task.

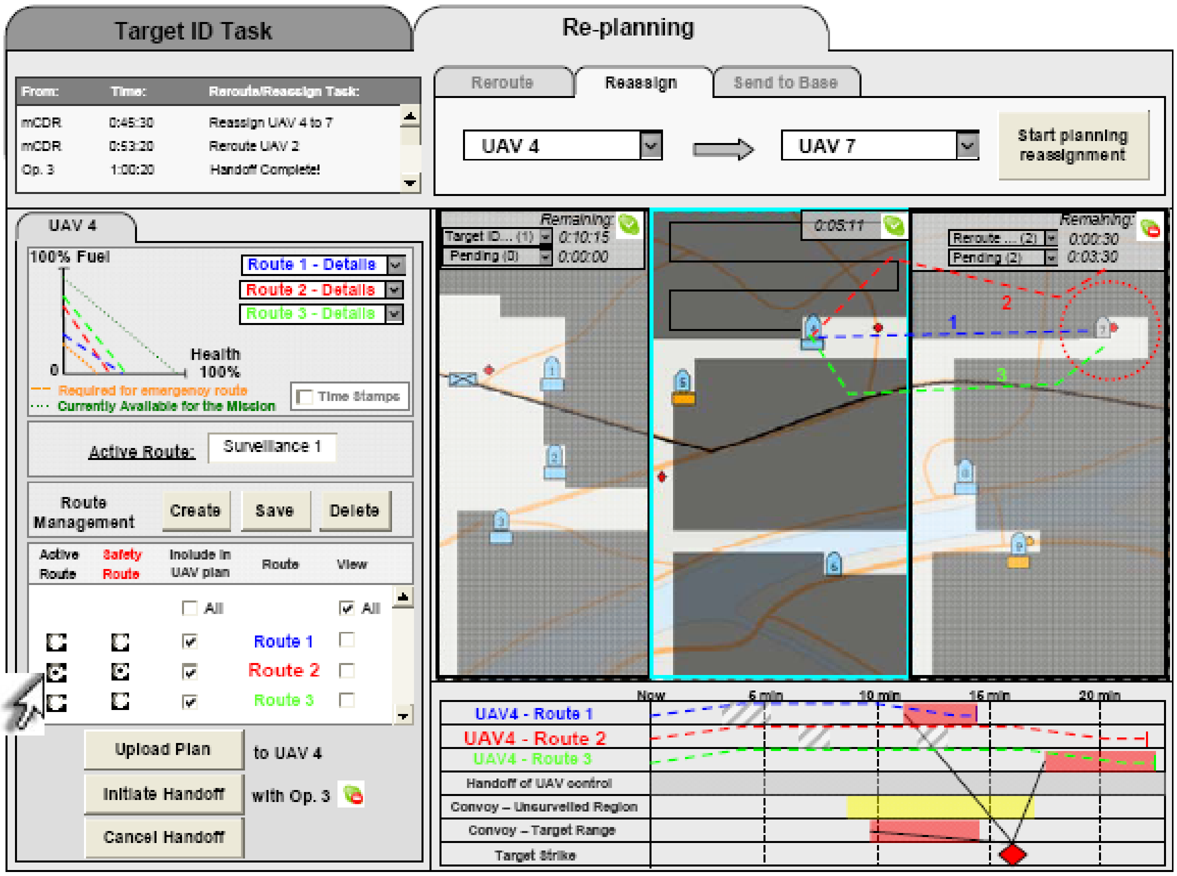


Figure 5.28 – Reassignment display with 3 routes

The operator must now choose some of the planned routes and send them to the UAV (with the definition of the active and the safety route). Figure 5.29 shows the starting operator uploading the route plan to the UAV.

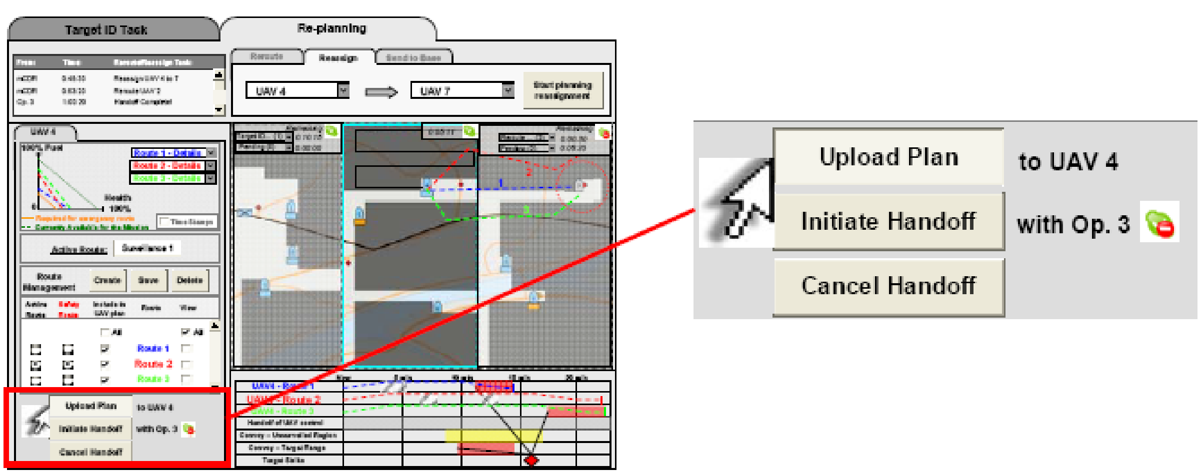


Figure 5.29 - Uploading the routes

Once the operator sends the plan to the UAV, he/she receives a confirmation message (to make sure he/she is uploading the correct plan) (Figure 5.30).

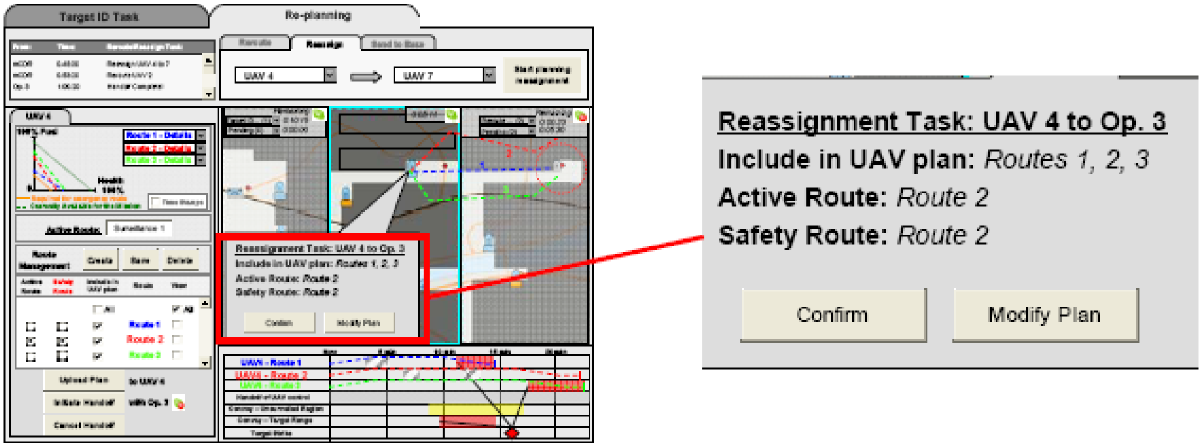


Figure 5.30 - Plan confirmation

Once the operator confirms the plan, the UAV starts following the defined active route, represented, now, by a continuous line (Figure 5.31).

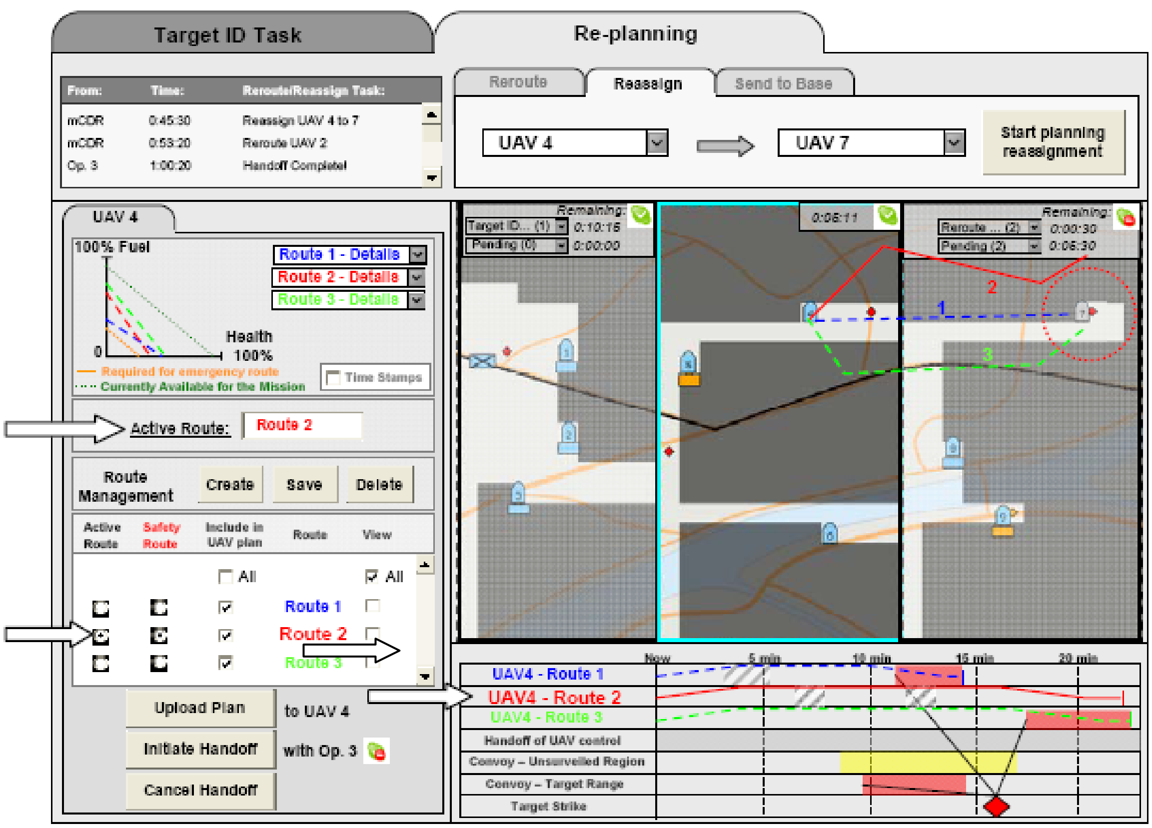


Figure 5.31 - UAV starts following the planned route

At this point, the starting operator initiates the UAV handoff coordination with the receiving operator.

Figure 5.32 - Initiating handoff

5.2.4 CDPD – From step 16 to the end

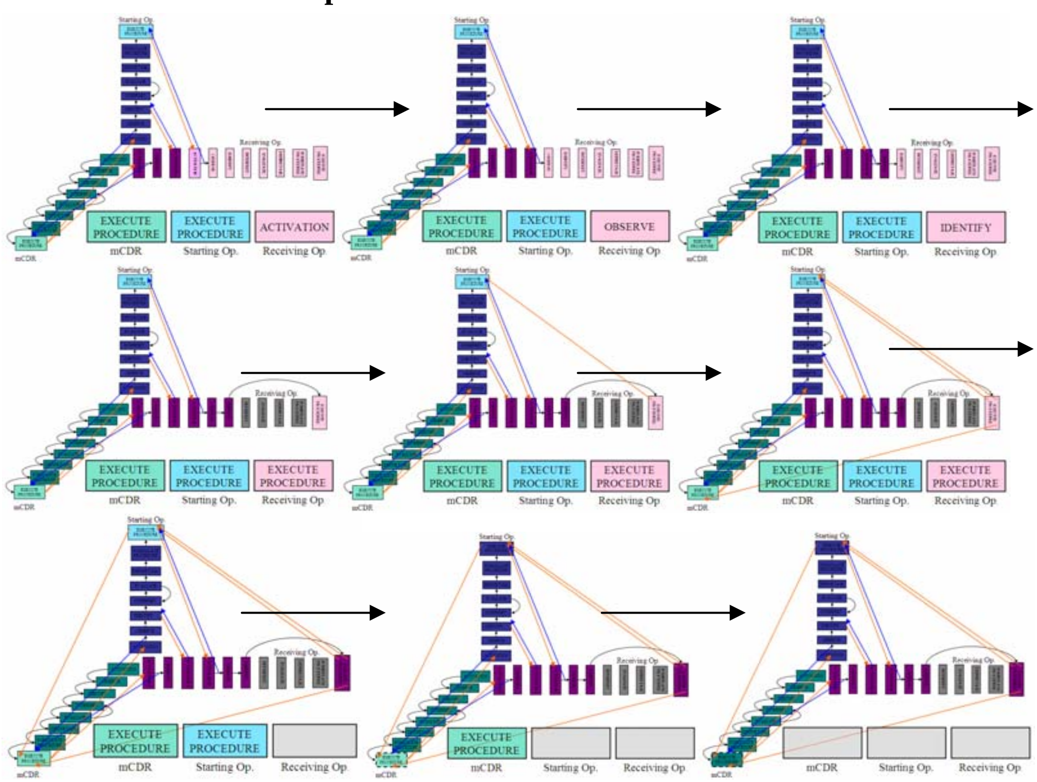


Figure 5.33 - CDPD – From step 16 to the end

Once the starting operator clicks the "initiate handoff" button, the UAV to be reassigned starts blinking in every display, for both operators. A landmark in the timeline indicates the moment when the handoff is expected to occur (based on the receiving operator current and near future activities). This landmark helps both operators coordinate the moment of the change in the UAV control.

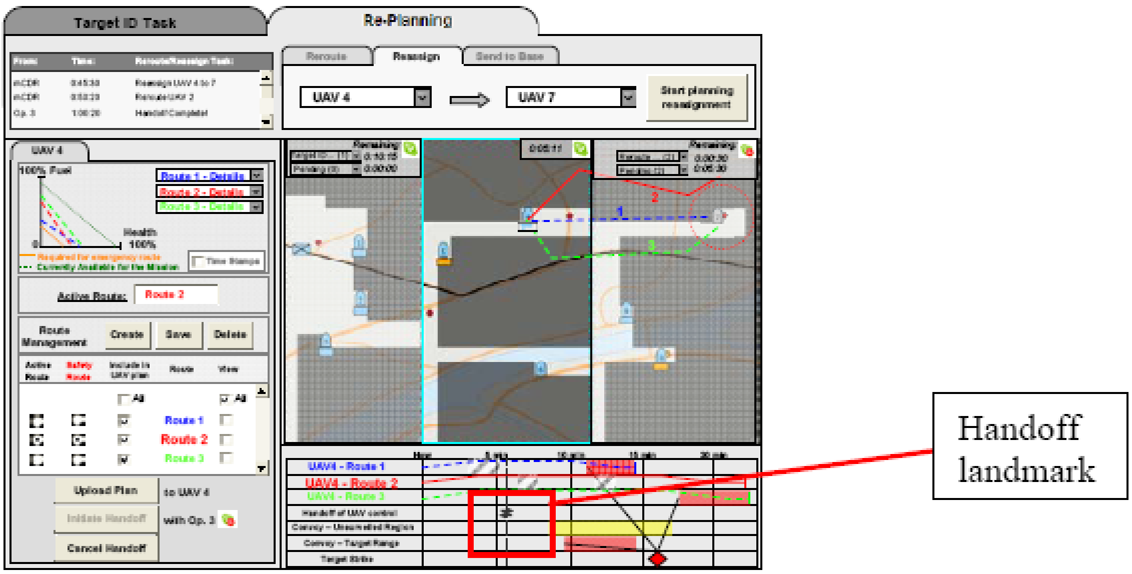


Figure 5.34 – Starting operator's reassignment display after clicking the "initiate handoff" button

At this point, the receiving operator's re-planning tab is blinking in orange and black. The receiving operator cannot make any modifications in the route management (buttons are grayed) before he/she assumes the UAV control.

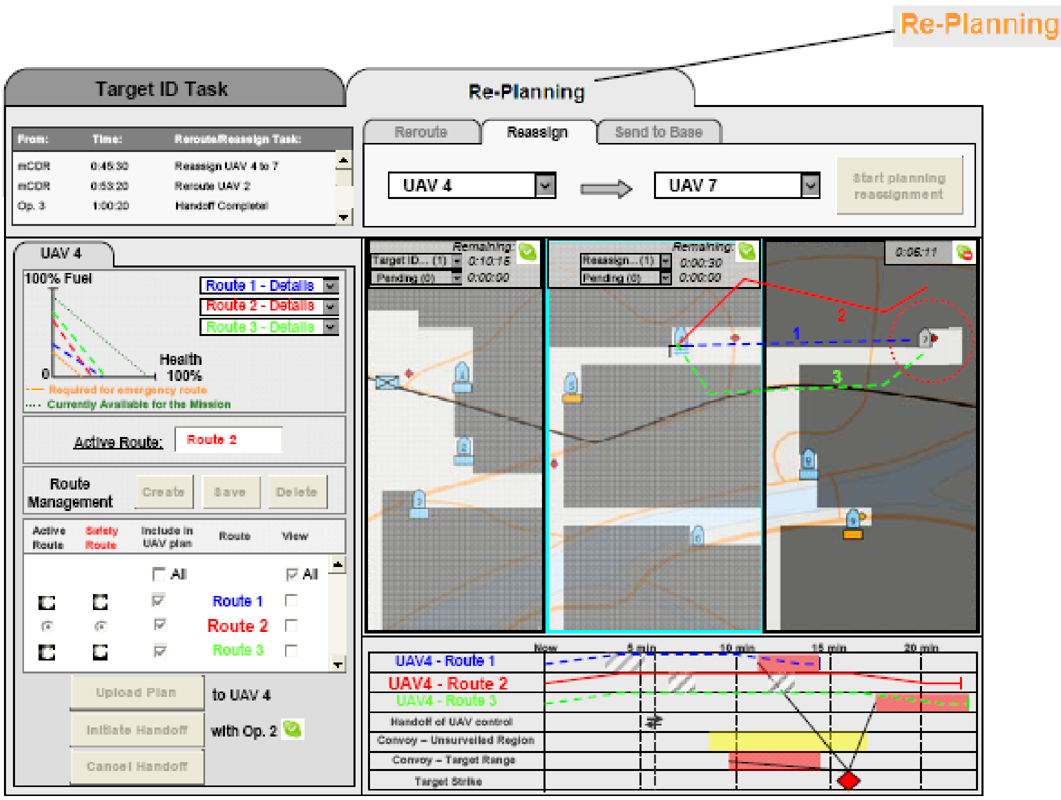


Figure 5.35 - Receiving operator's reassignment display ("initiate handoff" button clicked by starting operator)

As mentioned, the UAV will blink in every screen for both operators: Figures 5.36 to 5.38 present the map, the communication and the target ID display for the receiving operator right after the handoff request from the starting operator. If the receiving operator slides the mouse over the blinking UAV he/she will receive a notice about the handoff.

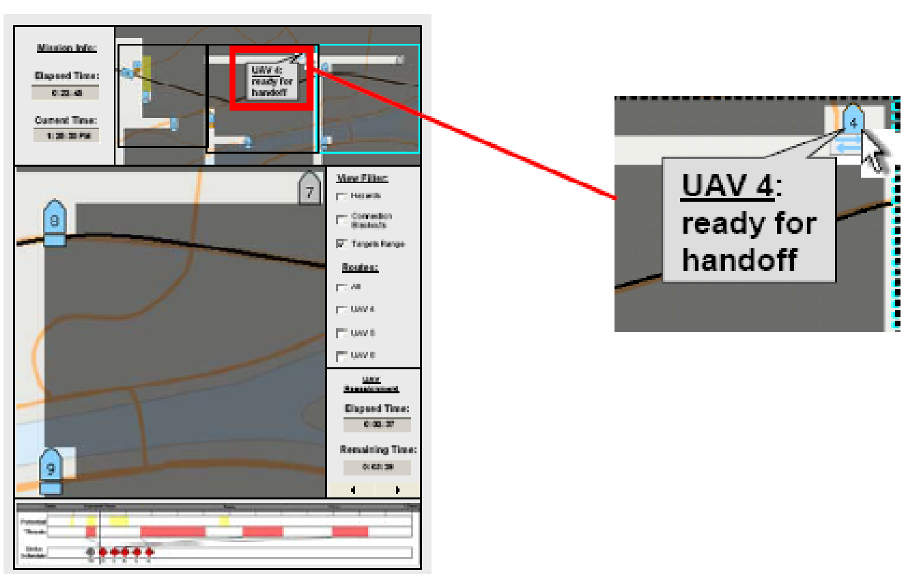


Figure 5.36 - Receiving operator's map display ("initiate handoff" button clicked by starting operator)

In the communication and in the target ID displays, the shot down UAV gives place to the UAV that is being reassigned (Figure 5.37):

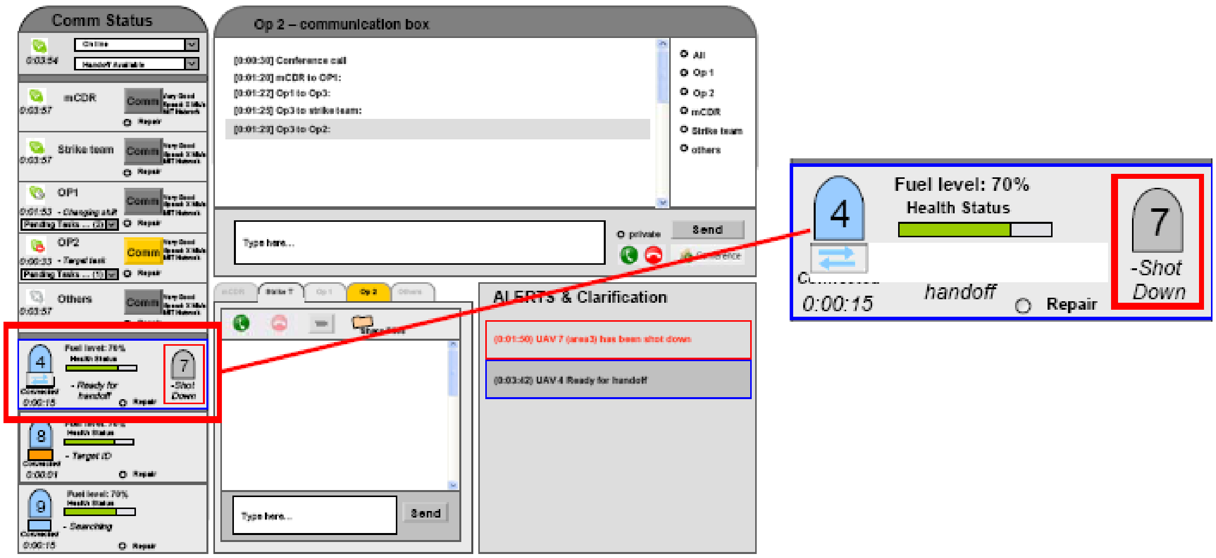


Figure 5.37 - Receiving operator's communication display ("initiate handoff" button clicked by starting operator)

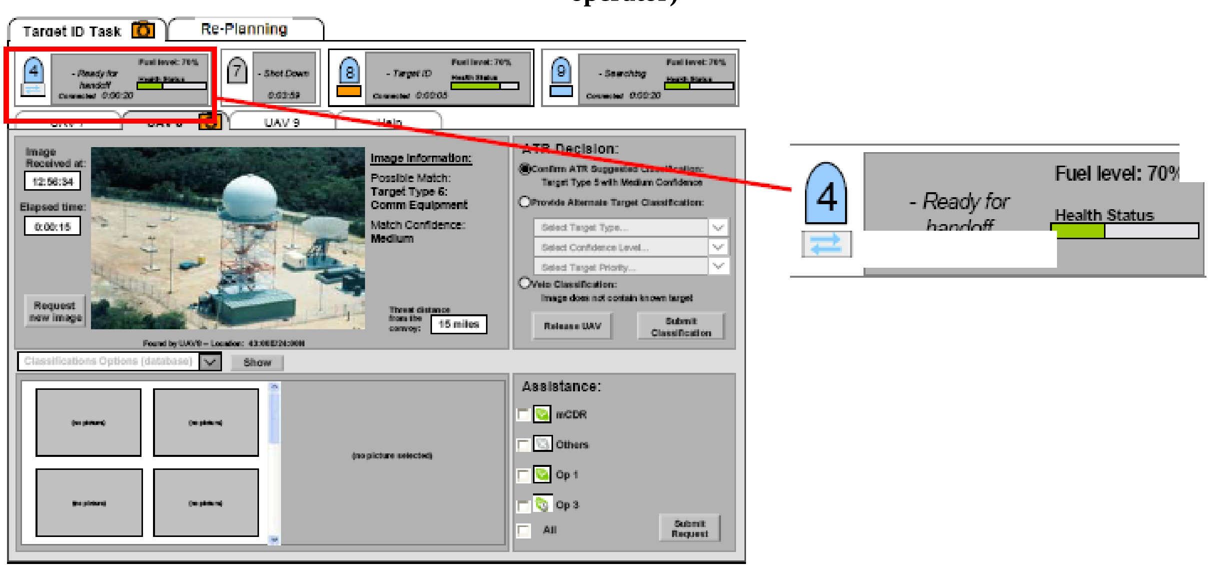


Figure 5.38 - Receiving operator's target ID display ("initiate handoff" button clicked by starting operator)

It can be seen in the previous figures (Figures 5.36 to 5.38) that there are redundancies in every display to make the receiving operator aware of the handoff request. Thus, it does not matter in which activity the receiving operator is involved, he/she will perceive the request.

In order to accept the handoff, the receiving operator must click the UAV and answer to the message that will pop up from it (Figure 5.39). The receiving operator has the option to accept the handoff or to delay the decision (in case he/she is too busy at the moment).

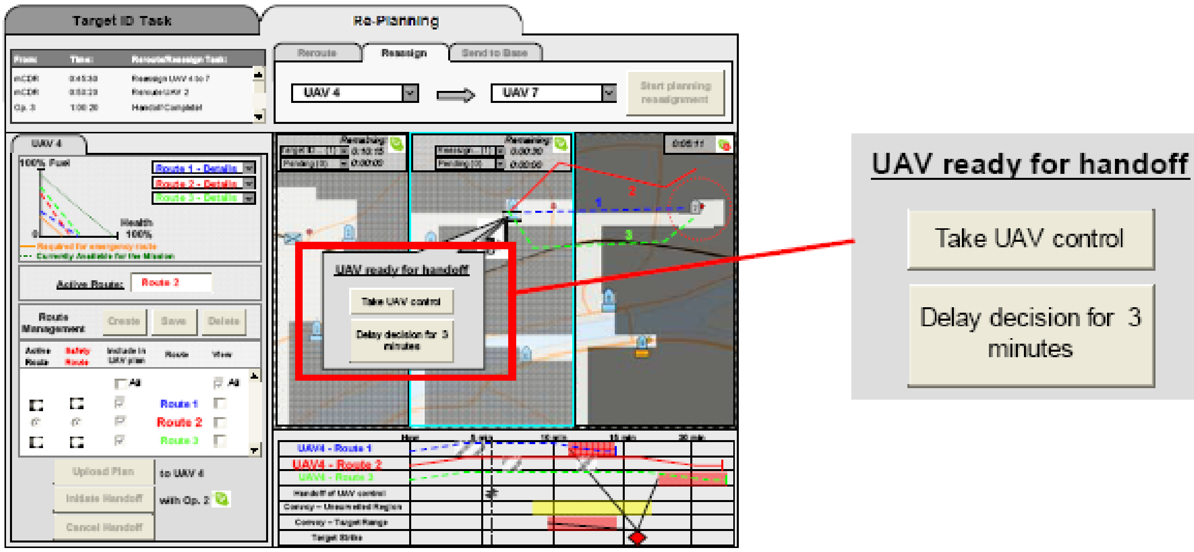


Figure 5.39 - Receiving operator's options

When the receiving operator accepts the handoff request and takes the UAV control, he/she will be able to alter the routes in the route management box.

Figure 5.40 – Receiving operator's reassignment display right after the handoff of the UAV control

At this point the UAV stops blinking and the starting operator stops seeing the information about the reassigned UAV. A message is sent to the mission commander informing him/her that the handoff is complete.

Chapter 6 Conclusion

This report proposed an extension of an existing CTA design methodology, the Hybrid CTA, motivated by the problem that this methodology limits the potential for overall UAV systems operations by not supporting adequately the collective decision making and coordination that is actually required throughout UAV mission operations. The result of this work was the development of a method that derives information and functional requirements aimed at supporting collaboration, communication, and coordination among UAV system operators.

This chapter presents a brief discussion of the contributions made by this research as well as the future directions that may be followed to extend this work. First, it is discussed how the initial goals set in Chapter 1 were addressed. Then the contributions made by this work are summarized. Finally some possible future work that could be derived from this research are presented.

6.1 Research Goals

The central research hypothesis of this work was that examining specific roles of team members in a collaborative task would help us identify information and functional requirements related to teamwork aspects (e.g. communication, collaboration and coordination) in the operation and control of complex systems.

This hypothesis was verified through the following goals:

- **Goal 1.** To develop a method to take into account teamwork in the requirements derivation for interfaces design for complex systems operation and control.

- **Goal 2.** To apply the developed method to re-design UAV system displays.

Both research goals were reached and the results obtained were presented in the previous chapters. The resultant displays, designed from requirements obtained with the developed Hybrid CTA Collaborative Extension method present stronger teamwork support than the original displays designed from the original Hybrid CTA.

6.2 Contributions

The main contribution given by this work is the method itself. The Hybrid CTA Collaborative Extension method can be used to design complex systems in a wide variety of applications involving teamwork with distributed members. The method gives a solid support to collaboration, coordination, and communication, which are important aspects of supporting collective decision making.

6.3 Future Work

The major issue with the obtained method is its complexity. An extension of this work must have as its first goal the simplification of the method, since it currently involves many steps and some steps are extremely arduous, extensive, and time consuming.

Another possible future research to be derived from this research is a full evaluation of the method, through real implementation and testing. By testing the designs obtained with the method, using real users, a better notion would be obtained of how well the method maps the environment and the dependencies between team members in comparison with other existing methods.

Acknowledgments

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Appendix A The Hybrid CTA Details

A.1 Scenario Task Overview

As described in Chapter 2, this step of the Hybrid CTA method presents the mission's goal and phases (and also the sub-goals in each phase and operator's individual sub-tasks). There are three main phases associated with the UAV ground force protection task: mission planning, mission execution and mission recovery. This study focuses on developing support for the mission execution (which may involve some mission replanning). It is assumed that the tasks of the formal mission planning have been completed prior to our task scenario.

Within the UAV ground force protection task there are five basic phase goals and event types: launch UAVs phase, ISR (Intelligence, Surveillance and Reconnaissance) (e.g., scouting the area in search of potential enemies), target detection (e.g., confirming target identified by the UAVs' onboard target identification systems), target schedule (e.g., receiving acknowledgement from the external strike team that a detected target has been scheduled to be destroyed) and UAV reroute/reassignment (e.g., planning new route for UAV). There are also off-nominal events that the UAV team may need to handle while executing the mission scenario: a UAV could be shot down (or become incapacitated due to equipment malfunction) and the UAV team could lose their communications link to one or more of their external contacts (i.e., the convoy, the strike team, or JSTARS).

Table A-1 details the expected or possible tasks and subtasks of the UAV team, and in particular of the multi-UAV operators during each of these basic and off-nominal phase events.

Finally once the mission has been executed, the UAV team will need to recover the deployed UAV assets. This mission recovery phase, may involve recalling the UAVs to a nearby base or re-tasking them to another mission. This study will only nominally consider this phase of the mission, as it is not our current focus.

Table A-1 - Operator CTA Task Scenario Overview

<table>
<tr><td rowspan="2">Mission Planning</td><th>Issues to be resolved in this phase:</th><th>Helpful information for resolving these issues:</th></tr>
<tr><td>– Each operator will have a pre-defined area under his/her responsibility
– Each operator will have a pre-defined # of UAVs under his/her responsibility
– Initial search area for Search UAVs will be determined
– Initial mission route for each UAV will be determined (Choose a pre-defined initial route for each UAV)
– Plan safety route</td><td>– Visual indication of area under his/her responsibility;
– Mission clock;
– UAV surveillance speed;
– Engaged time (operator target confirmation time, communication time with strike team, mission commander and UAVs, strike team schedule timing);
– Average time that target recognition will take;
– Visual indication of search areas/ tactical map;
– Expected convoy arrival time, path;
– Suggestions of possible UAV routes/ Visual indication;
– Ideal range of UAVs for accurate ATR (Automatic Target Recognition);
– UAVs endurance/health status (fuel, physical conditions)</td></tr>
<tr><td rowspan="4">Mission Execution (Basic phases/events)</td><th>Phase Goals</th><th>Phase Breakdown</th></tr>
<tr><td>Launch UAVs Phase</td><td>– Launch Search UAVs</td></tr>
<tr><td>ISR (Intelligence, Surveillance & Reconnaissance)</td><td>– UAV Operator monitors AOI while UAVs search for potential threats
– Monitoring health status</td></tr>
<tr><td>Target Detection</td><td>– UAV's onboard ATR sends a potential target alert to the controlling UAV Operator
– UAV Operator examines ATR to confirm or refute target identification
– If it is a target: process target ID information/ classification
– Possibility to request mission commander's help</td></tr>
<tr><td rowspan="2">Mission Execution (Basic phases/events)</td><td>Target Schedules</td><td>– Check strike team and mission commander's availability
– Submit target information details to strike team (high or low priority, target classification and position)
– Send message of target confirmation to mission commander
– UAV goes back to searching task
– Feedback of target scheduling from strike team</td></tr>
<tr><td>UAV reroute/reassignment</td><td>– mission commander requests a UAV task modification
– UAV operator communicates intentions to mission commander
– UAV operator performs route modifications
– UAV operator confirms the modification</td></tr>
<tr><td rowspan="2">Mission Execution (Possible off-nominal events)</td><td>UAV shot down</td><td>– All operators and mission commander are notified about the UAV loss
– Target being confirmed added to strike team schedule (If UAV was shot down by a known target)
– Notification whether mission commander decided to reassign another UAV from another operator's AOI</td></tr>
<tr><td>UAV malfunction</td><td>– The operator responsible for this UAV is notified about malfunction
– UAV Operator recalls UAV to base if necessary
– UAV Operator Alerts mission commander of modifications</td></tr>
<tr><td>Mission Recovery</td><td colspan="2">Once the Mission Execution Phase is completed - or is aborted - UAVs should be recalled to base or re-tasked to another mission</td></tr>
</table>

A.2 Event Flow Diagram

The event flow diagram sketches the mission execution phase into sequential events and lists mission planning assumptions. In this step, the events (tasks and sub-tasks) temporal organization and dependencies and the temporal constraints are presented.

Three basic event types are used: loops (iterative events that occur until another predetermined event arises), decisions (an event requiring knowledge-based input from an operator), and processes (a task requiring some human-computer interaction).

Figure A.1 depicts the event flow diagram constructed from the scenario task overview. The gray rectangles at the top show the three main mission phases: mission planning, mission execution, and mission recovery. Below the mission planning phase is a parallelogram listing the tasks which are assumed to be completed prior to the mission execution phase (our primary concern): each UAV operator is given a pre-defined area of surveillance (their AOI), the number of UAVs assigned to each AOI is defined and each UAV area, search route and safety route is defined.

In the event loop diagram, diamonds depict decisions, hexagons represent loops, and rectangles depict processes involving human-computer interaction. Each decision results in a yes or no answer, which leads to another event. Dotted boxes indicate decisions and related processes that were deemed complex enough to be expanded into decision ladders.

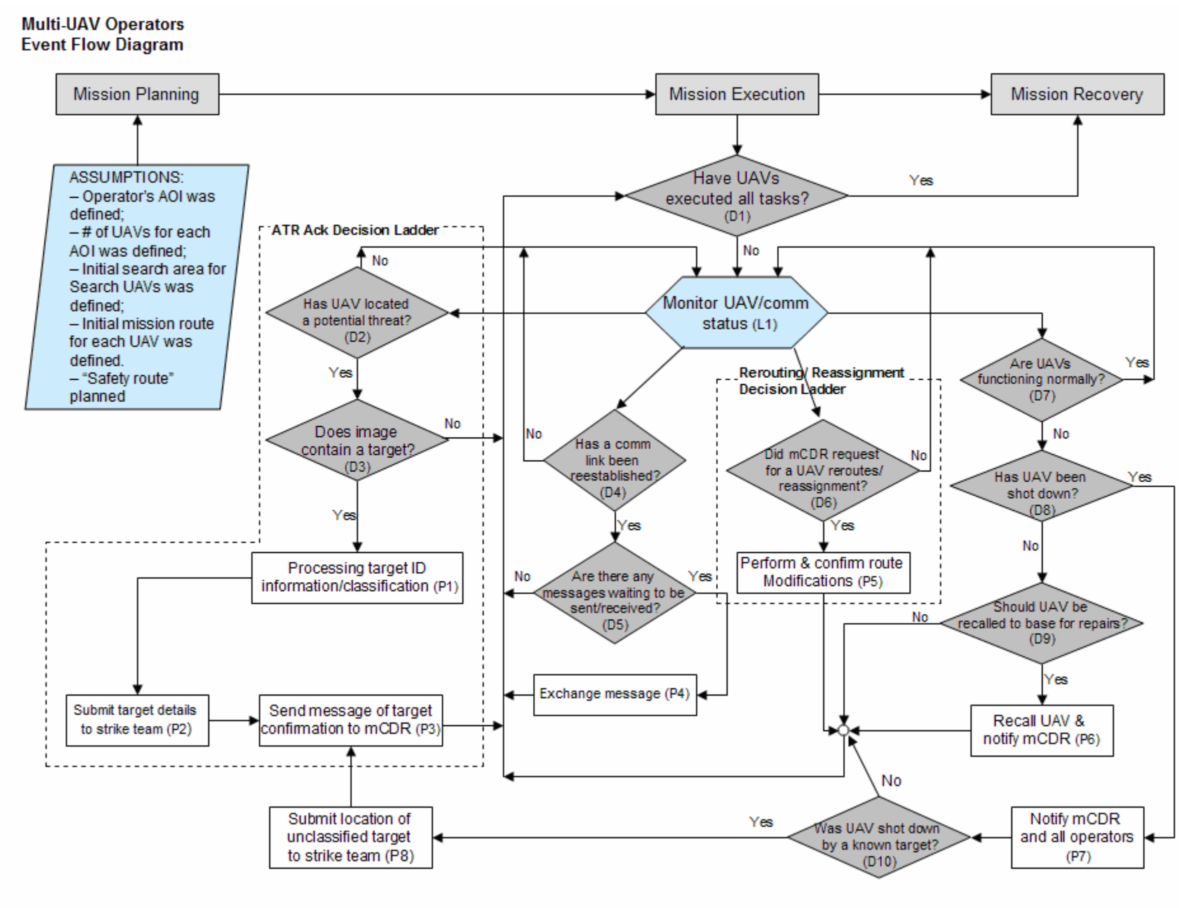


Figure A.1 - Event Flow Diagram

For the multi-UAV operators, the main mission execution decision (D1) establishes if the UAVs from that AOI have executed all tasks. If the UAVs have executed all tasks, the mission proceeds to the third and final phase, mission recovery. Otherwise, the operator enters a monitor UAV/communication status loop (L1). Monitoring the UAV/communication status consists of watching out for two main things: the status of UAVs and the communication status with other team members.

If any UAV from that AOI finds a potential threat (D2), the operator needs to decide whether the imagery sent by the UAV contains a target or not (D3). If the image(s) contains a target, the operator classifies this target (P1), submits target details to the strike team (P2), and sends a target confirmation to the mission commander (P3). The operator may also need to re-task a UAV. This activity may be activated by a strict request from the mission commander (D6) or if a UAV is not functioning normally (D7). In case of malfunctioning, and if one of the operator's UAV has been shot down (D8) the operator needs to notify mission commander and the other operators about it (P7). If the operator determines that the UAV was shot down by a known target (D10), they will submit the target details to strike team (P8). In the meantime, the operator must be aware of possible communication losses, and when communication links become reestablished (D4) in order to assure that messages are sent and received appropriately.

A.3 Situation Awareness

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

The SA requirements for the nominal and off-nominal events which may occur during the mission execution phase of the UAV ground force protection task are detailed in Table A.1, Appendix A.1. The SA requirements listed in this table focus on the information that the UAV team, and in particular the multi-UAV operators, may need to perceive and comprehend the current state of the UAV status and the team's communication status and to predict the future state of these issues throughout the tasks within each mission event (as listed in the Scenario Task Overview, Table A.1).

Note: The letters and numbers (e.g. D1) in the following table are associated with the event flow diagram from Figure A.1.

Table A-2 - Operator CTA Situation Awareness Requirements

Phases/Events	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)
Launch UAVs	- Visual indication of operator's AOI (D1, L1, P5)	- Visual indication of each UAV route (when requested) (D1, L1, P5, D9)	- Ability to visualize possible UAV routes (D1, L1, P5) - Visual indication of current UAV route in geo-spatial context (D1, L1, P5, D8, D9)
ISR	Visual indication of: - Geo-spatial boundaries (D1, L1, D2, P1, P8, P5, D6, D8, D9) - Tactical map (D1, L1, D2, P1, P5, D7, D8, D9) - Locations of all UAVs assigned to each operator's area (D1, L1, D2, P1, P5, D8, D9, P8) - Locations of all UAVs reassigned to each operator's area (D1, L1, D2, D6, P5, D8, D9) - UAVs' current activities (searching, loitering, down) (D1, L1, D2, P1, P5, D7, D8) - Communication link status with UAVs (D1, L1, D2, P1, D4, P5, D6, D7, D8, P6) - UAVs' health status (D1, L1, D2, P5, D7, D8, D9) - Limitations of camera angle view (P1) - Mission Time (D1, L1)	- Error message/alert clarification (P1, P2, P3, P4, P5, P6, P7,P8, D5) - UAVs' monitoring performance (visual indication on tactical map) (D1, L1, D2, P1, P5, D7, D8, D9) - Communication chat with mission commander (if needing help) (D3, P1, P3, D4, D6, P5, P6, P7) - Position of found targets should be displayed on tactical map (D1, L1)	- Surveilled & unsurveilled area displayed on tactical map (D1, L1, P5, D9) - Communication link status (D1, L1, P1, P2, P3, P8, D4, P6, P7) - UAVs limitations (D1, L1, D2, P1, P5, D7, D9) - Uncertainties - Strike Team limitations (P2, P8) - UAVs' expected health status (D1, L1, P5, D9) - Area Constraints (no fly zone, current threats, etc) (D1, L1) - Estimated time for the UAV to start the safety route in case of lost communication with operators (D1, L1) - Indicate areas in AOI known to cause communication connection losses (D1, L1, P1, P5, D9, P6, D10)
Potential Threat/Target Detection	- Alert of potential threat detection from UAV (D2, D10) - Time of potential threat discovery (D2, D10) - Indicate which UAV detected potential threat (D2, P1) - Indicate potential threat position (P1, P8) - Indicate UAV camera capabilities (D3, P1) - Indicate camera angle and range during image capture (D3, P1) - Indicate possible match for the threat classification (D3, P1) - Match confidence (D3, P1) - Visual indication of convoy's current position (P1) - Re-alert operator if he/she is taking too long to start potential threat classification (L1) - Communication link status with the UAVs (L1, D2, D3, D4, P1, D5, P4)	- Show image of potential threat (D3) - Show options for potential threat classification (e.g.: vehicle, headquarters, strategic, not a target) (P1) - Ability to request for an updated image from UAV (D3, P1) - Elapsed time since the potential target was detected (L1) - Ability to request for mission commander to help with threat classification (D3, P1, D4, D5, P4) - Ability to share threat classification info with mission commander (and others) (D3, P1) - Show mission commander's (or other Ops or any other local authority) threat classification (D3, P1) - Ability to compare ATR image received with others images (database) (D3, P1) - Show operator classification for the threat (D3, P1, P2, P3)	- Estimated distance range of target to convoy (P8, P1, P2) - Estimated priority of target with respect to mission goals (P1) (High, medium, low priority) - Indicate the target's weapons range on tactical map (L1)

Table A-2 - Operator CTA Situation Awareness Requirements (cont'd)

Phases/Events	Level 1 (Perception)	Level 2 (Comprehension)	Level 3 (Projection)
Target Schedule	- Communication status with mission commander and with strike team (D3, P1, P2, P3, P8, D4, D5, P4) - Target ID information (P2, P8)	- Schedule of known target strikes (L1, D4, D5, P4)	- Expected availability of strike team in the context of mission activities (D4, D5, P4)
UAV reroute/ Reassignment	- Alert when mission commander requests a UAV reroute/reassignment (D5, D6) - Indicate if UAV has been shot down or reassigned or JSTARS was requested (D7, P3, D8, D9, D6, P5) - UAVs' health and communication status (D6, D7, D8) - UAVs' current routes, location & activities (L1, P3, D6, D8, P5, D7, D9, D2) - Handoff operator identity & activities (D6, P5) - Visual indication of surveilled & unsurveilled area (L1, D1, P5)	- Convoy position (mission goal) (P5) - Convoy route (D1, L1, P5) - Ability to browse pre-programmed routes options (based on number of UAVs in AOI & convoy location) (P5) - Ability to make a manual route adjustment on the pre-programmed route and save solution (P5) - Ability to request assistance (P5)	- Indication of route modifications (P5, L1) - Indication of UAV following this new route (L1) - Ability to compare possible route options ("what if") (P5) - Expected time to surveil critical area (P5) - Expected mission time for each UAV (D1, L1, P5) - Expected time of arrival of UAV in reassigned area/location (P5, D1, L1) - Time requirements of possible new UAV routes in relation to mission time &/or convoy route (P5) - Operator constraints (if applicable) (P5)
UAV shot down	- Alert of target attack (D7, D8, D10) - UAV ID (D8) - Time UAV was attacked (D8) - Position of UAV (D8)	- Indication of whether UAV was destroyed by an unknown or known target (D7, D8, D10)	- Further intelligence about target that attacked the UAV (D10, P8) - Whether any UAVs are available for reassignment (D6)
UAV malfunction	Alert operator if (D7): - Fuel / fluids pressure is too high - UAV is overheating - Camera is malfunctioning - UAV has been attacked/shot down Indicate: - Fuel status (D7, D9, P5) - Temperature status (D7, D9, P5) - UAV's health status (injury/death) (D7, D8, D9, P5) - Communication link status with injured UAV (D4, D5, P4, D7, D9)	- Convoy position (D9) - Communication link with mission commander to notify about the malfunction & possible UAV re-task (D4, D5, P4, P6, P7)	- Safety route (L1) - Indicate if system is approaching any safety thresholds for pressure / heat / electronics / etc (D7) - Indicate endurance of UAV under the current conditions (technical details of system failures) (D7, D9) - Estimated time UAV would survive without addressing malfunction (D9, P5) - Estimated time for UAV to return to base, get repaired, & go back to the surveillance task (D9, P5)
Communication with: UAVs mission commander Strike team	- Alert when link is lost or regained to any external contact (L1, All Ps, D4) - Indicate current communication link status for all stakeholders (D4)	- Indicate how long any link has being down (D4)	- Predicted communication connections among stakeholders (D4)

A.4 Decision Ladders

The next step of the CTA attempts to articulate an operator's potential thought process by generating decision-ladders. Since this work focuses on the reroute/reassignment task, the decision ladder associated to this task is the only one to be presented here.

Figure A.2 depicts the decision-making process for determining an appropriate UAV route modification ((D6), Figure A.1). This decision would be made when the UAV operator received an order from the mission commander to reroute or reassign a UAV in the AOI, likely in response to a critical event that is affecting the team's surveillance performance (e.g., a downed UAV). The operator needs to perceive the request and determine which UAV(s) are involved, the current area constraints, and if appropriate, the receiving operators' availability (in the case of a reassignment) and any related temporal conflicts and/or UAV limitations. In order to select an appropriate route for the UAV re-tasking, the operator can access a route database, make manual adjustments in pre-programmed paths or create his own route. The ability to compare various route requirements, such as time, fuel and endurance, would facilitate this process. Once an appropriate route is chosen, the UAV operator must send the plan modifications to the appropriate UAV(s) and to the appropriate operator (if applicable).

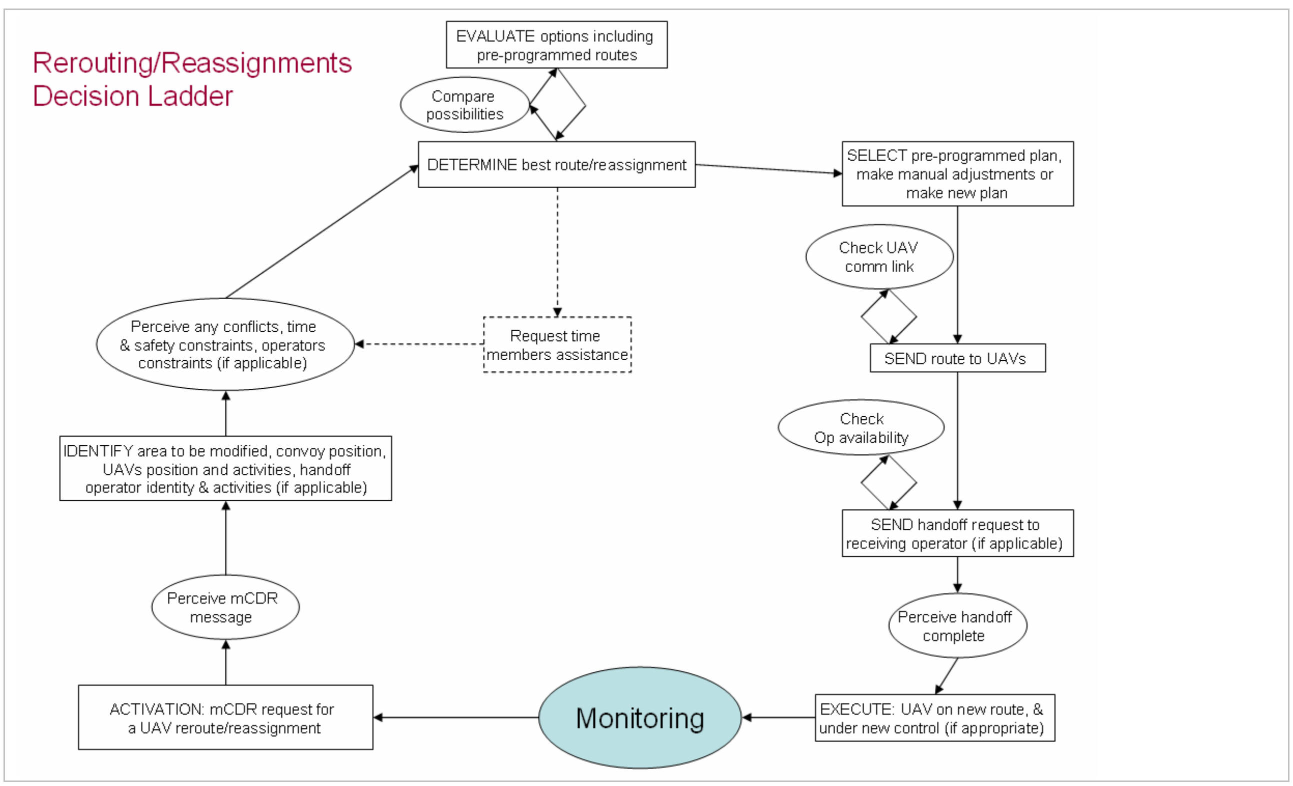


Figure A.2 - Decision ladder leading to rerouting/ reassignments.

A.5 Summary of Requirements Generated from the CTA

The CTA produced a wide variety of information requirements for supporting the multi-UAV operators during the UAV ground force protection task. These requirements can be broadly categorized as requirements for providing geospatial information, alerts & feedback information, communication & availability, team information, vehicle related requirements, temporal information, target ID task requirements, and reassignment/ rerouting task requirements. These requirements are summarized in Table A.3 grouped by these broad categories. For each requirement the table also indicates whether it originated from the analysis of the situation awareness requirements (SA), from the display requirements detailed in the decision ladders (Display) and/or from the collaboration awareness requirements detailed in the decision ladders (CA).

The requirements obtained through the Hybrid CTA method related to the reassignment task will be added to the requirements generated by the Hybrid CTA Collaborative Extension method and a new table will be the outcome of the new method.

Table A-3 - Summary of requirements generated by the CTA

Type	Requirement description	Source
Geospatial Info	Tactical map	SA
	Visual indication of operator's AOI	SA
	Number of UAVs assigned each this AOI	Display
	Visual indication of geo-spatial boundaries	SA
	Visual indication of convoy's current position & planned route	SA & Display
	Visual indication of UAVs path in geo-spatial context	SA
	Display UAVs' current & future positions and path	SA & Display
	Visual indication of surveilled & unsurveilled area	SA & Display
	Area constraints (no fly zones, current threats, etc)	Display
	Indicate if there's a region in the AOI where communication is difficult to connect	SA
	Indicate potential/known threat position	SA & Display
	Estimated distance range of target to convoy	SA
	Visual indication of UAV route modification	SA
	Visual indication of UAVs being reassigned to a new area/operator	Display
Alerts & Feedback Info	Error message/alert clarification	SA
	Alert (visual & audible) of potential threat detection from UAV	SA & Display
	Alert when mission commander requests a UAV reroute/reassignment	SA
	Alert of unsuccessful data or communication exchange	Display
	Alert if pressure is too high	SA
	Alert if UAV is overheating	SA
	Alert if camera is malfunctioning	SA
	Alert if UAV has been attacked / shot down	SA
	Alert if the operator is taking too long to start the potential threat recognition	SA
	Alert when some link is lost or regained to all the contacts	SA
	Feedback of scheduled target strikes	SA & Display
	Handoff message confirmation	Display
	Indicate if UAV (under the team members' control) have been shot down, reassigned or JSTARS was requested	SA
Communication & availability	Strike team comm link status (with time info): Online, busy, offline or disconnected.	SA, Display & CA
	Communication link status with the UAVs (connected/disconnected)	SA, Display & CA
	Mission commander's comm link status (with time info): Online, away, busy, in a call, offline & disconnected.	SA, Display & CA
	Op's comm link status (with time info): Online, away, busy (rerouting, reassignment, target classification), changing shift, offline & disconnected.	SA, Display & CA
	Communication link status with injured UAV (connected/disconnected)	SA & CA
	Operator constraints	Display
	Handoff/ Receiving Op’s communications availability	SA & Display
	Current communication connections among stakeholders	SA
	Predicted communication connections among stakeholders	SA
	Expected availability of strike team in the context of the mission activities	SA, Display & CA
	Strike Team weapons capability & availability	SA
	Connection's signal strength, speed, duration & network (Possible to repair)	CA
	Show other options to communicate with relevant team member	CA
	Show whether other contact is available to assist Op	CA
Team Info	Whether other UAVs are available for reassignment if UAV is attacked or malfunctions	SA
	Handoff/receiving operator identity & activities	SA & Display
	ID/Position in the context of the mission activities of UAV attached/ shot down	SA
Vehicle Related Requirements	Op's UAV's system & health status (fuel/ oil temperature/ destroyed)	SA & Display
	Safety route	SA
	Predictions of Op's UAVs health status	SA
	Indicate current UAVs' location & activities and planned UAVs' location & activities	SA
	Indication of endurance of Op's UAV under the current conditions (technical details of system failures)	SA
	UAVs limitations	SA

Table A-3 - Summary of requirements generated by the CTA (cont.)

Type	Requirement description	Source
Temporal Info	Mission Time	SA
	Time that the potential threat was discovered	SA
	Elapsed time since the potential target was found	SA
	Time that the UAV has been shot down/ attacked	SA
	Expected time to surveil critical area	SA
	UAV potential endurance without repair after a malfunction	SA
	Estimated time for UAV to return to base, get repaired, & go back to the surveillance task upon UAV malfunction	SA
	Indicate how long the communication link has been disconnected	SA & Display
	Estimated time for UAV to start safety route in case of lost communication with operators	SA
	Elapsed time of active operator task	Display
	Estimated time for reassigned UAV to arrive in new area	SA & Display
	Estimated time for a relevant team member to perform a task	CA
	Average time that a team member performs a particular task	CA
	Predicted time UAV is going to be inside an difficult connection region	CA
	Elapsed time UAV remained in difficult connection region	CA
	Expected mission time for each UAV	SA
Target ID Task Requirements	Indicate which UAV is detecting potential threat	SA & Display
	Indicate camera angle and range during image capture	SA & Display
	Camera capabilities (Parameter for imagery change request, Limitations of camera angle view)	SA & Display
	Show image of potential threat	SA & Display
	Ability to request a new image	SA
	ATR classification & match confidence	SA & Display
	Show options for potential threat classification (e.g.: Not a target, Vehicles, Comms Equipment)	SA
	Ability to compare ATR image received with other images from a database	SA
	Target of interest database (show pictures of similar targets, or expected targets)	Display
	Ability to request help from mission commander (or other Ops or any other local authority) with threat classification task	SA & Display
	Ability to share threat classification info with mission commander (and others)	SA
	Indicate whether a local weapons authority is available or if there is any new intel on weapons in the area	Display
	Show mission commander (or other Ops or any other local authority) classification for the threat	SA & Display
	Estimate importance of the target to the mission goal	SA
	Show operator classification for the threat	SA
	Further intelligence about the target that struck the UAV	SA
	Indicate whether the target was destroyed by an unknown or known target	SA
Reassignment/ Rerouting Task Requirements	Indicate route modification request	Display
	Indicate which UAV is going to be reassigned & its position	SA
	Indicate current route for relevant UAVs	SA
	Visual indications of possible pre-planned route (for rerouting task)	SA & Display
	Ability to request assistance from others	SA & Display
	Ability to make a manual route adjustment on the pre-programmed UAV routes and save solution	SA
	Ability to browse saved UAV routes suggested for comparison	Display
	Ability to compare possible routes options ("what if")	SA
	Show fuel/endurance requirements for each possible route in the context of mission time requirements	Display
	Time requirements for each UAVs' possible new routes (in relate to the mission time &/or convoy route)	SA & Display

Appendix B Hybrid CTA Collaborative Extension Details

B.1 Details about the Role Specific Decision Ladders

B.1.1 Mission Commander Role Specific Decision Ladder

a) After the “identify” step of the decision ladder , the mission commander must be able to answer at least the following questions about four of the main aspects involved in his/her decision:

1. Threats

Had the shot down UAV detected many targets in that region (it may be dangerous to send another UAV there)?

Are there constraints (hazards, connection blackouts) in this region?

Are there extra information about this region (is it an especially dangerous region?).

2. Coverage

How much of the region (percentage of total flyable region) had already been covered by the shot down UAV?

How much of the other UAVs’ regions have already been covered?

3. Operators & UAVs Usability

What task the shot down UAV was performing?

What is the current connection, status and activities (and near future activities) of the 3 operators and their activities importance for the whole mission?

How is the performance of the 3 operators? (It may not be adequate to ask a low performance operator to send or receive a UAV)

What are the closest (1st , 2nd,…) UAVs to reassign?

What are their (closest UAVs) current and near future activities?

Are there regions of constraint in a straight line between these (closest) UAVs' current positions and the region they would be supposed to be sent to?

Are there other kinds of vehicles constraints (e.g. time, fuel, endurance, UAVs' limitations (e.g. velocity))?

4. Feasibility

Is there enough time to perform a reassignment? (related to the overall mission time performance/distance to convoy)

Wouldn't a reroute of the UAVs from the same region (in which the UAV was shot down) solve the problem? (related to the distance from the convoy to the region/coverage of the region).

b) At the "interpret" step of the decision ladder, the mission commander predictions must involve the following aspects:

- Consequences of choosing to execute the reassignment in terms of:

1. Safety: UAVs and convoy safety, number of targets already detected in the region, environmental constraints

2. Coverage: percentage of coverage, strategic importance of the region

3. Operators & UAVs usability: operators' performance, operators' current and near future tasks, importance of the task the shot down UAV was performing, UAVs' constraints

4. Feasibility: mission performance, time constraints

- Consequences of choosing the UAV for the reassignment in terms of:

1. Safety: convoy and UAV safety.

2. Coverage: Percentage of coverage of the (possibly) reassigned UAV area.

3. Operators & UAVs Usability: current and near future activities of the operator responsible for the UAV, current and near future activities of the UAV, UAVs' constraints.

4. Feasibility: distance from the area it would be sent to, time constraints

B.1.2 Starting Operator Role Specific Decision Ladder

The detailed relevant aspects to be identified by the starting operator are:

1. Geospatial Info: UAV to be reassigned: current and near future position, shot down UAV position, environmental constraints (hazard areas, blackout connection areas, other relevant UAVs' routes and position).

2. Safety: Location of already detected targets.

3. UAV to be reassigned: activities, endurance, fuel, UAV characteristics (velocity of surveillance and of cruise – to calculate time to complete route)

4. Receiving operator's availability: with respect to current and expected tasks (duration, difficulty of the tasks), with respect to connection (current and in the near future).

B.1.3 Receiving Operator Role Specific Decision Ladder

In the "identify" step, the receiving operator must be concerned with the following aspects:

1. Convoy position: to evaluate the importance of the reassignment against his current activities.

2. Receiving operator's availability: current and near future activities (performed by his UAVs and by himself/herself.)

3. Environmental constraints (in receiving operator's area) & safety of his/her UAVs: hazard areas, blackout connection areas and relative position of his/her UAVs' to these regions. Existence of detected targets in the programmed path of his/her UAVs (a reroute of a threatened UAV may be more immediately necessary)

B.2 Collaborative Decision Process Diagram (CDPD)

CDPD walkthrough:

The first steps of the CDPD correspond to the mission commander decision ladder walkthrough. The mission commander does not interact with other team members along these steps, thus they are not represented in here. However, they are described in detail in the item 4.2.1.

Table B-1 – CDPD walkthrough

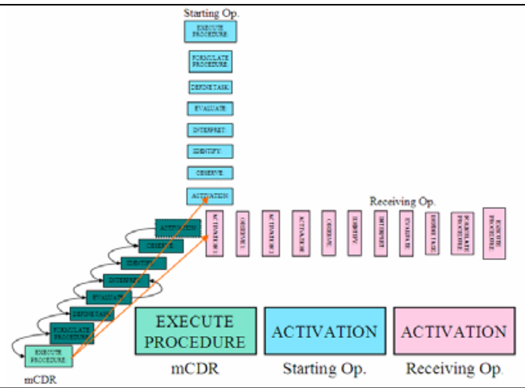
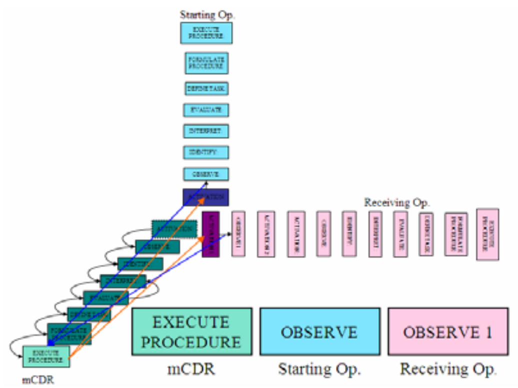
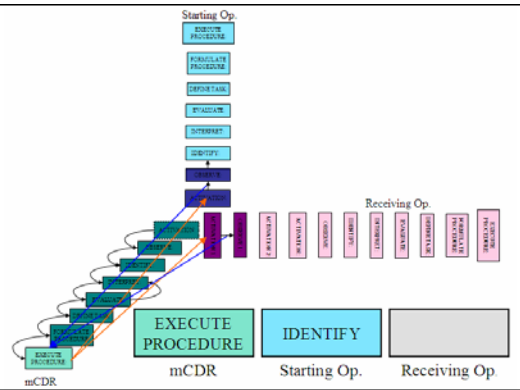
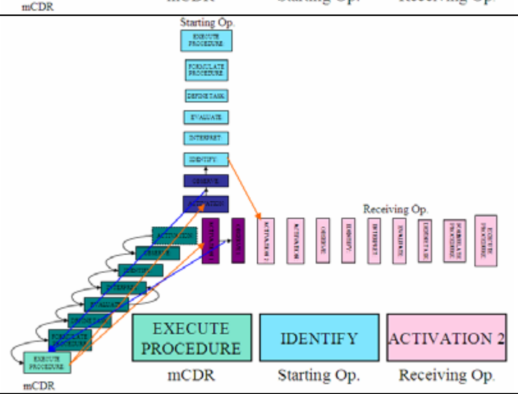
	When the mission commander is decided about the reassignment, he/she activates the operators involved in the task (orange arrows).
	After the activation, the operators send confirmation messages to the mission commander (blue arrows) informing they are aware of the reassignment request. After sending the confirmation, both operators observe which the UAV to be reassigned is and who is sending/receiving it. At this point, they can also notice if there are constraints imposed by the mission commander over the task.
	The starting operator starts identifying the scenario in order to plan the routes and the receiving operator works on other activities in the meanwhile.
	The starting operator sends a message to the receiving operator informing he/she is about to start planning the routes (orange arrow).

Table B-1 – CDPD walkthrough (cont.)

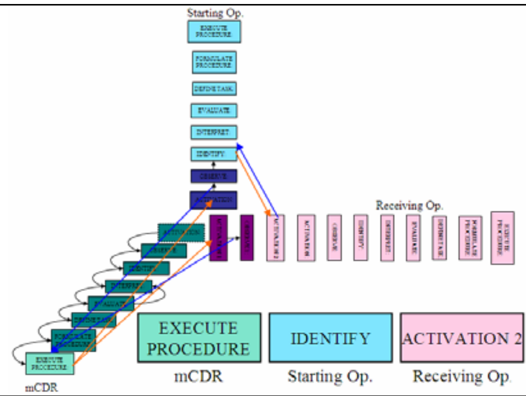
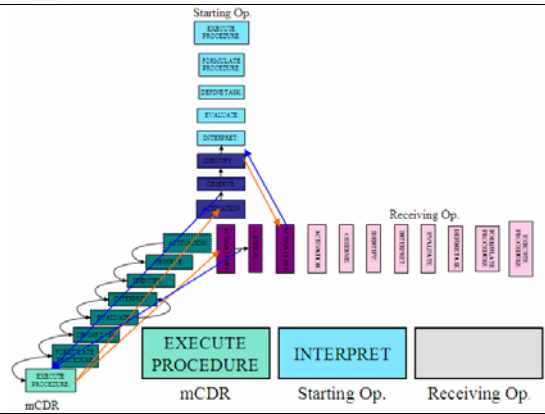
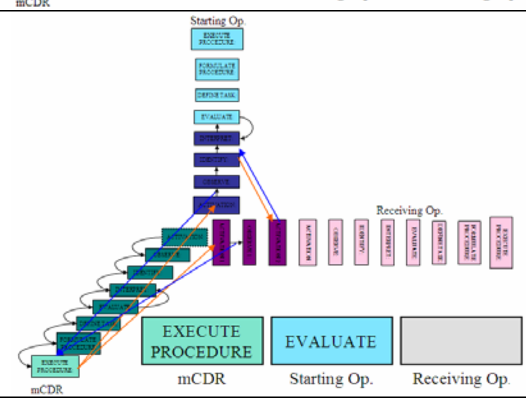
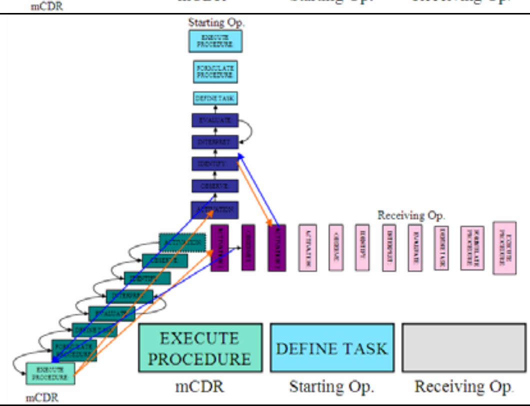
<table>
<tr><td>
</td><td>The receiving operator sends a message to the starting operator confirming he is aware that the routes are starting to be planned (blue arrow).</td></tr>
<tr><td>
</td><td>Starting operator works on the route planning.</td></tr>
<tr><td>
</td><td>Starting operator works on the route planning.</td></tr>
<tr><td>
</td><td>Starting operator has already planned the routes and is working on final changes before sending them to the UAV.</td></tr>
</table>

Table B-1 – CDPD walkthrough (cont.)

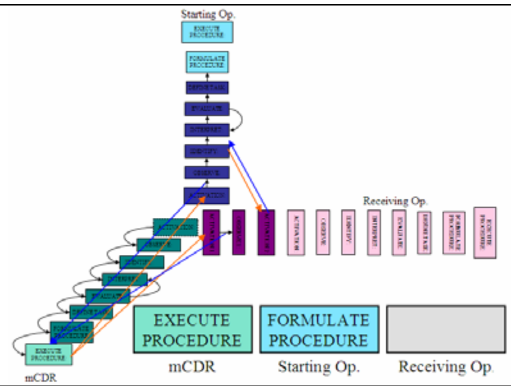
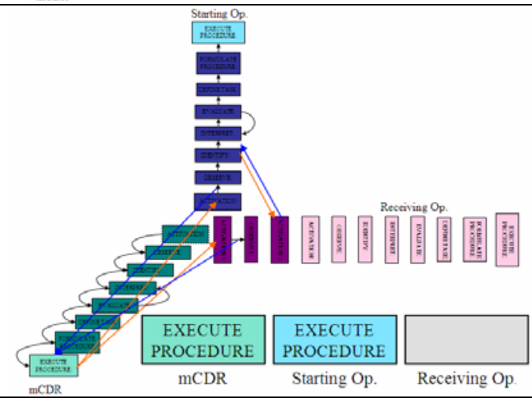
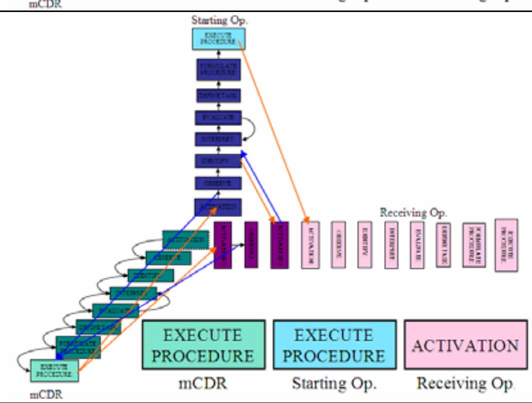
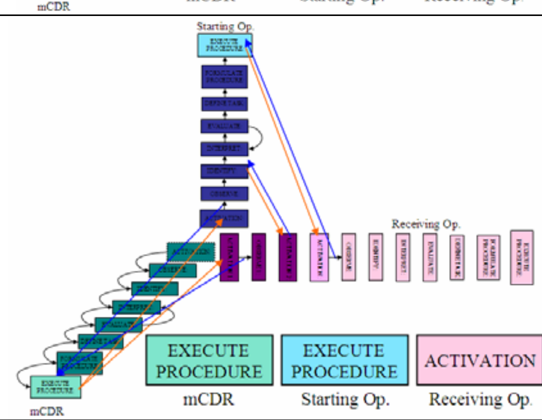
<table>
<tr><td>
</td><td>Starting operator is planning the procedure of sending the UAV for the reassignment.</td></tr>
<tr><td>
</td><td>Starting operator starts executing the procedure. The planned routes are sent to the UAV.</td></tr>
<tr><td>
</td><td>Starting operator sends a message to the receiving operator requesting the handoff of the UAV control (orange arrow).</td></tr>
<tr><td>
</td><td>Receiving operator sends a message to the starting operator confirming he/she is aware of the handoff request (blue arrow).</td></tr>
</table>

Table B-1 – CDPD walkthrough (cont.)

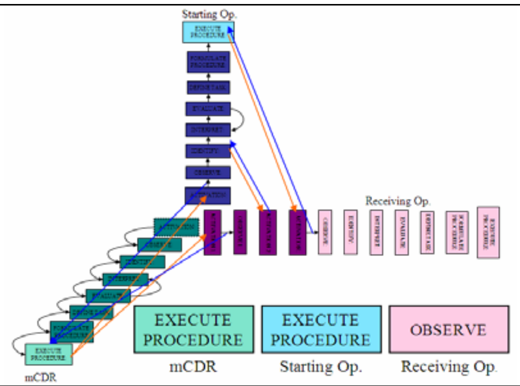
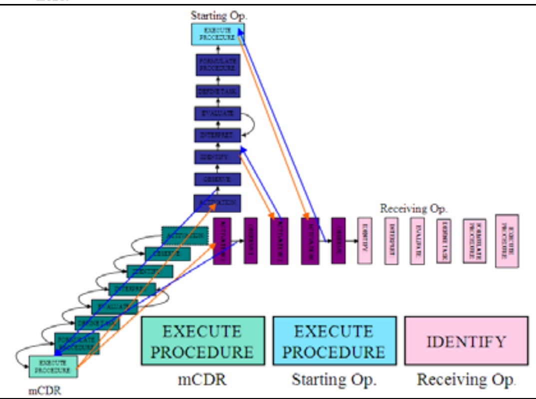
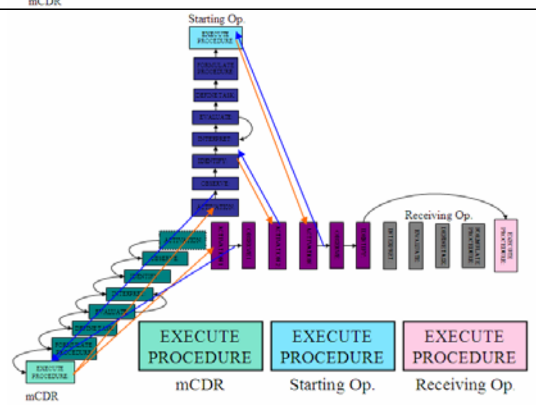
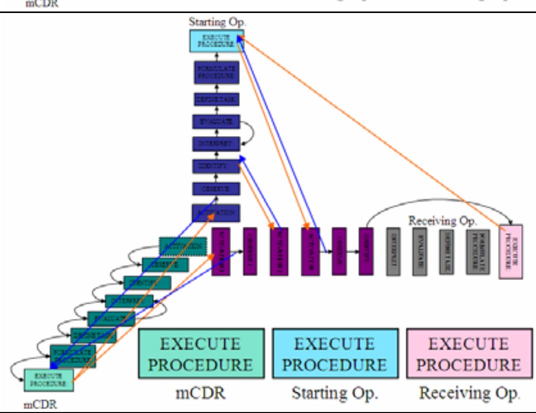
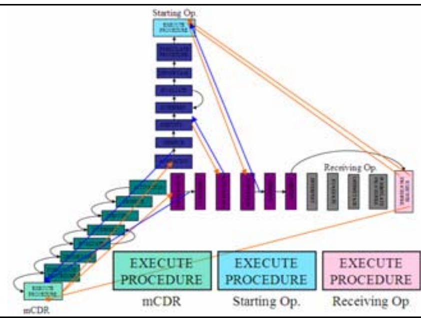
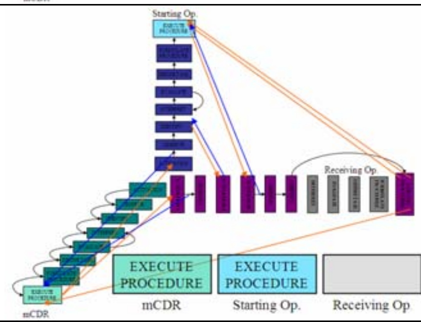
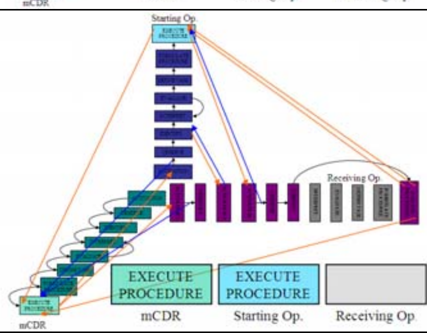
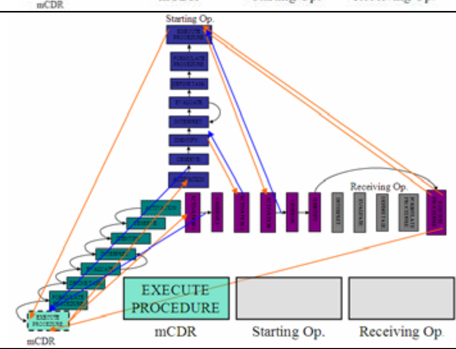
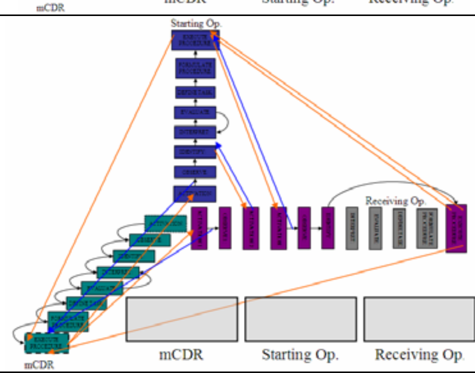
<table>
<tr><td>
</td><td>Receiving operator observes the reassignment route duration.</td></tr>
<tr><td>
</td><td>Receiving operator identifies all the information necessary to decide when to get the UAV control.</td></tr>
<tr><td>
</td><td>Receiving operator has already decided when he is assuming the UAV control.</td></tr>
<tr><td>
</td><td>Receiving operator sends a message to the starting operator informing when he/she will get the UAV control.</td></tr>
</table>

Table B-1 – CDPD walkthrough (cont.)

	Receiving operator assumes the UAV control and sends messages to the starting operator and to the mission commander informing them about the change in control.
	Receiving operator has concluded his role in the task. Starting operator perceives he is no longer in control of the UAV.
	Starting operator sends a message to the mission commander informing he is aware of the change in the UAV control.
	Both operators have concluded their roles in the task. The mission commander perceives the task has been accomplished.
	The task is complete.

B.3 Misperception of UAV states

Table B-2 – Misperception of the Surveillance State

What are the possible consequences of not perceiving a state?			
What is the state?	Who should have perceived state?	Who is controlling UAV?	
		Starting operator	Receiving operator
Surveillance	Mission commander	- May incorrectly stop convoy - May incorrectly request reroute/reassign of another UAV (possible collision)	
	Starting operator	- May not perform target ID. - May keep UAV loitering over target at low altitude. - May not send target classification to strike team. - May incorrectly reroute his UAVs (possible collision). - May believe UAV is being reassigned to another operator (possible ambiguity of responsibility for the UAV). - May incorrectly assume that receiving operator's region will be surveilled soon.	- Since handoff of the control has already been accomplished, there are no major consequences if starting operator does not perceive the UAV's state.
	Receiving operator	- May wrongly believe the UAV is being reassigned and abandon an important activity to receive it.	- May not perform target ID. - May keep UAV loitering over target at low altitude. - May not send target classification to strike team. - If the handoff of control takes place in starting operator's region, receiving operator may wrongly expect that the UAV is being reassigned to his region.

Table B-3 – Misperception of the Transiting State

<table>
<tr><th colspan="4">What are the possible consequences of not perceiving a state?</th></tr>
<tr><th rowspan="2">What is the state?</th><th rowspan="2">Who should have perceived state?</th><th colspan="2">Who is controlling UAV?</th></tr>
<tr><th>Starting operator</th><th>Receiving operator</th></tr>
<tr><td rowspan="3">Transiting</td><td>Mission commander</td><td colspan="2">- May expect that areas over which UAV is flying are being surveilled, when, in fact the ATR system is turned off.</td></tr>
<tr><td>Starting operator</td><td>- May believe his region is still being surveilled by an already reassigned UAV (may delay a possible rerouting).
- May not get ready for the handoff (possible ambiguity of responsibility for the UAV).</td><td>- Since the handoff of control has already been accomplished, there are no major consequences if starting operator does not perceive the UAV’s state.</td></tr>
<tr><td>Receiving operator</td><td>- May not get ready for the moment of handoff (possible ambiguity of responsibility for the UAV).</td><td>- May expect target detection when the ATR is turned off.
- May not notice if UAV never leave transiting state.
- Possible collision with other UAVs at transiting altitude in the region.</td></tr>
</table>

Table B-4 – Misperception of the Non-Steady State

<table>
<tr><th colspan="4">What are the possible consequences of not perceiving a state?</th></tr>
<tr><th rowspan="2">What is the state?</th><th rowspan="2">Who should have perceived state?</th><th colspan="2">Who is controlling UAV?</th></tr>
<tr><th>Starting operator</th><th>Receiving operator</th></tr>
<tr><td rowspan="3">Non-Steady</td><td>Mission commander</td><td colspan="2">- There are no major consequences for the mission if mission commander does not perceive a non-steady state, but it is important that he is aware that the UAV has gone through this state when it was supposed to, otherwise mission commander may be confused about the current UAV state.</td></tr>
<tr><td>Starting operator</td><td>- May expect target detection when ATR is turned off.</td><td>- Since handoff of control has already been accomplished, there are no major consequences if starting operator does not perceive the UAV’s state.</td></tr>
<tr><td>Receiving operator</td><td>- Since UAV is not under his control and non-steady state happens quickly, there should be no major consequences if the receiving operator does not correctly perceive the UAV is in a non-steady state.</td><td>- May expect target detection when ATR is turned off.
- May not be ready to expect that UAV is about to start surveillance (and will possibly detect targets then).</td></tr>
</table>

B.4 Information Components & Levels of detail

Table B-5 – Information components and level of detail for the UAV as a boundary object

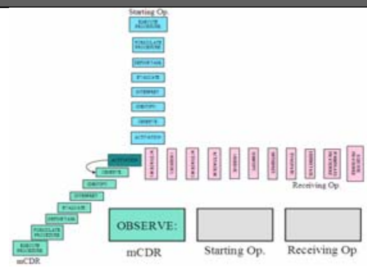
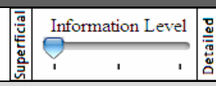
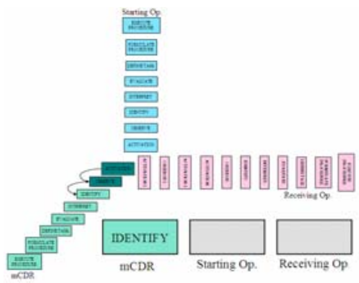
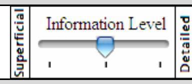
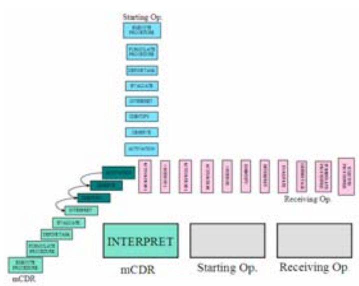
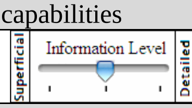
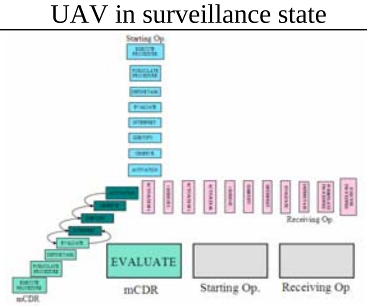
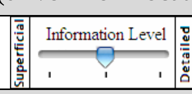
CDPD Step	Mission commander	Starting operator	Receiving operator
 UAV in surveillance state		-	-
	At this point, all the mission commander needs to know is which UAV has been shot down, he still has not started to think about which UAV he is reassigning.	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV.
 UAV in surveillance state			
	- UAV current & future activities - Overall fuel and health status (only shown if the UAV is expected to reach some critical level in a near future) - Connection status (only shown if it requires attention, if it is critical). - Operator in control of UAV - UAV number - UAV location - UAV capabilities	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV.
 UAV in surveillance state			
	- UAV current & future activities - Overall fuel and health status (only shown if the UAV is expected to reach some critical level in a near future) - Connection status (only showif it is critical). - Operator in control of UAV - UAV number - UAV location & estimated time to arrive at receiving operator's region (driven from location)	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV.
 UAV in surveillance state			
	- Same set of information from the previous step	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

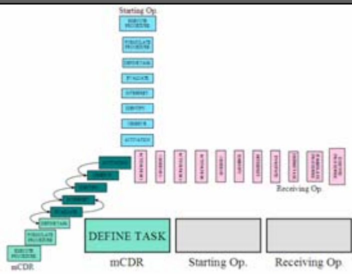
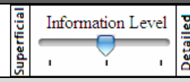
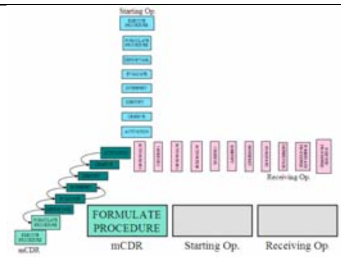
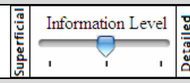
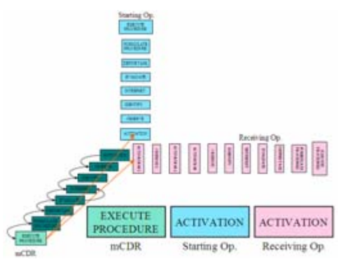
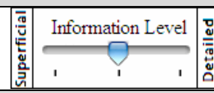
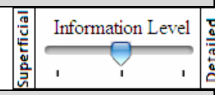
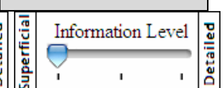
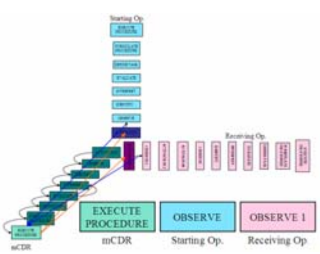
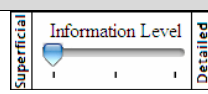
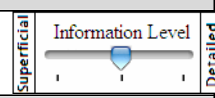
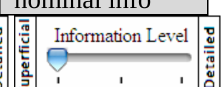
CDPD Step	Mission commander	Starting operator	Receiving operator
 UAV in surveillance state	 - Operator in control of UAV - UAV number - UAV location - UAV current and future activities - Critical information (about fuel, health, connection) if applicable	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV.
 UAV in surveillance state	 - Same set of information from the previous step	Starting operator still does not know he is sending a UAV	Receiving operator still does not know he is receiving a UAV
 UAV in surveillance state	 - Same set of information from the previous step	 - UAV number - UAV location	 - Operator in control of UAV - UAV number - UAV estimated time to arrive at receiving operator's region - UAV Location - Critical/off nominal info
 UAV in surveillance state	 - ATR on - UAV current and future activities - Surveillance speed, altitude and route (the overall notion of what it means to be in the surveillance state). - Operator in control of UAV - UAV number - UAV location - Critical information (about fuel, health, connection) if applicable.	 - Same set of information from the previous step	 - Same set of information from the previous step

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

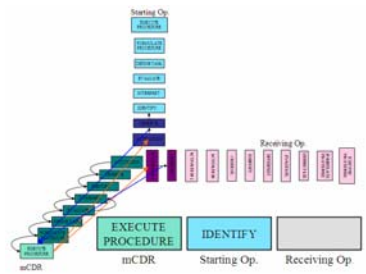
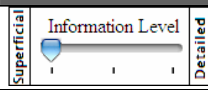
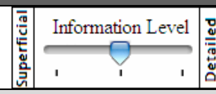
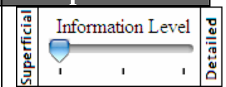
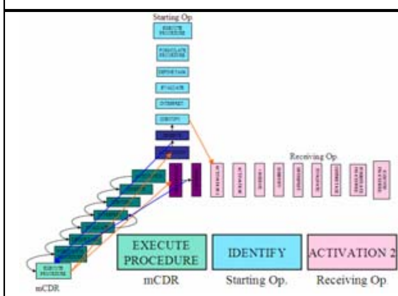
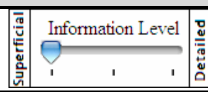
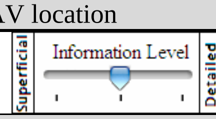
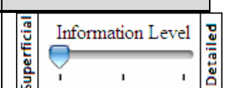
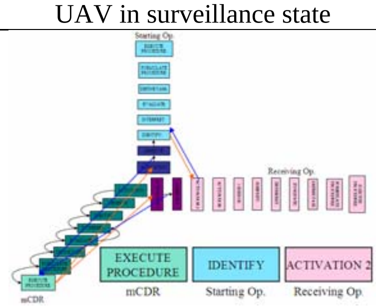
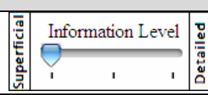
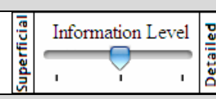
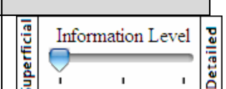
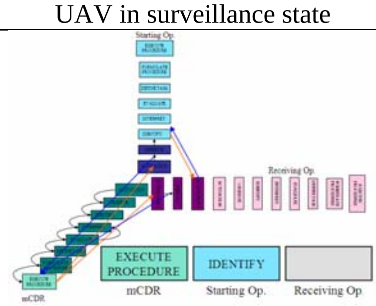
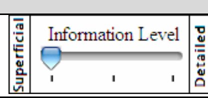
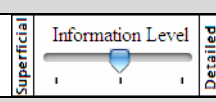
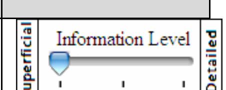
CDPD Step	Mission commander	Starting operator	Receiving operator
			
UAV in surveillance state	- Same set of information from the previous step	- ATR on - UAV current and future activities - Surveillance speed, altitude and route (the overall notion of what it means to be in the surveillance state). - Critical status information if applicable. (for feasibility check of reassignment) - Estimated time for the UAV to enter the target's range (target that shot down the UAV) - UAV location and estimated time of arrival in the receiving operator's region - UAV number - UAV location	- Same set of information from the previous step
			
UAV in surveillance state	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
			
UAV in surveillance state	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
			
UAV in surveillance state	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

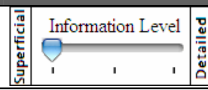
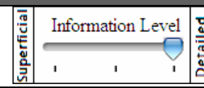
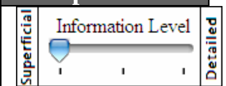
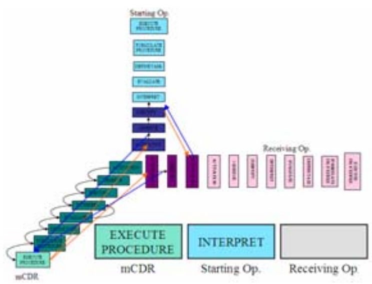
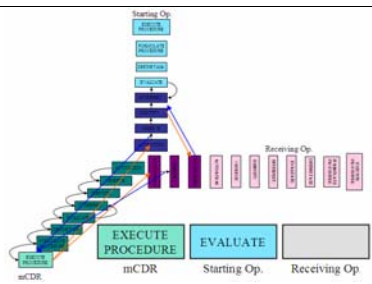
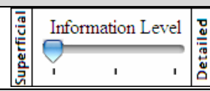
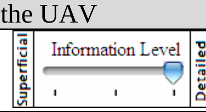
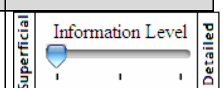
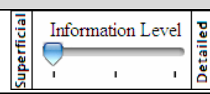
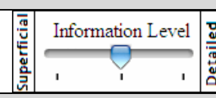
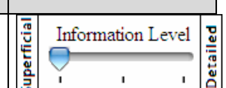
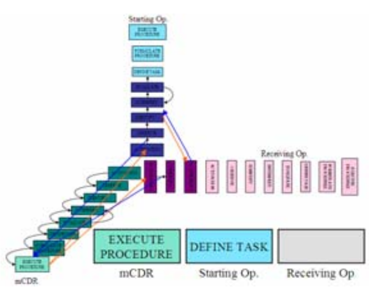
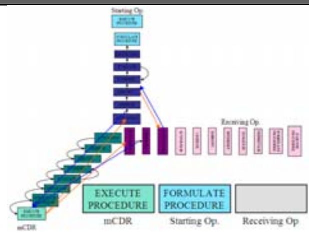
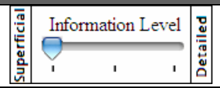
CDPD Step	Mission commander	Starting operator	Receiving operator
			
 UAV in surveillance state	- Same set of information from the previous step	- ATR on - UAV current and future activities - Surveillance speed, altitude and route - Detailed fuel and health status (current & expected for each route). - Connection: current & expected future status - UAV number - UAV location & estimated time of arrival in the receiving operator's region for each possible route - Estimated time to enter the range of the target that shot down the UAV	- Same set of information from the previous step
 UAV in surveillance state			
	- Same set of formation from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
			
 UAV in surveillance state	- Same set of information from the previous step	- ATR on - UAV current & future activity - Surveillance speed, altitude and route - Critical status information in off-nominal state - UAV number - UAV location & estimated time to arrive at receiving operator's region - Estimated time to enter the range of the target that shot down the UAV - Planned reassignment routes (nominal and safety)	- Same set of information from the previous step

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

<table>
<tr><th>CDPD Step</th><th>Mission commander</th><th>Starting operator</th><th>Receiving operator</th></tr>
<tr><td rowspan="2">

UAV in surveillance state</td>
<td>
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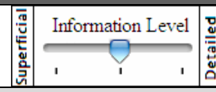
<td>
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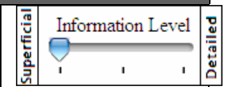
<td>
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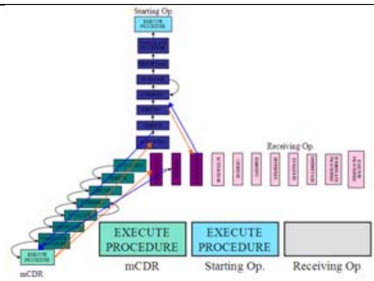
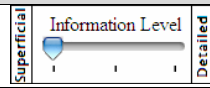
<tr><td rowspan="2">

UAV in surveillance state</td>
<td>
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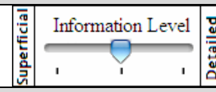
<td>
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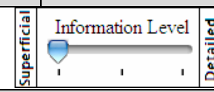
<td>
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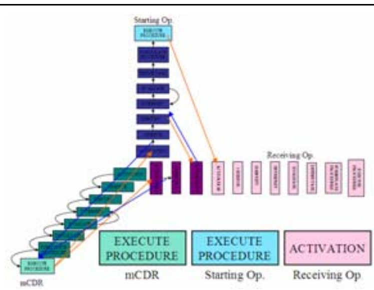
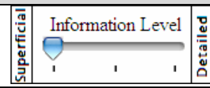
<tr><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td></tr>
<tr><td rowspan="2">

UAV in surveillance state</td>
<td>
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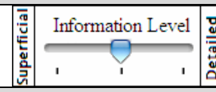
<td>
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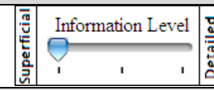
<td>
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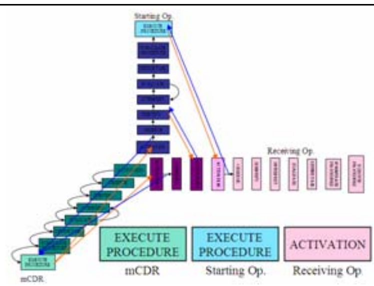
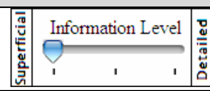
<tr><td rowspan="2">

UAV in surveillance state</td>
<td>
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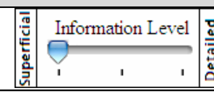
<td>
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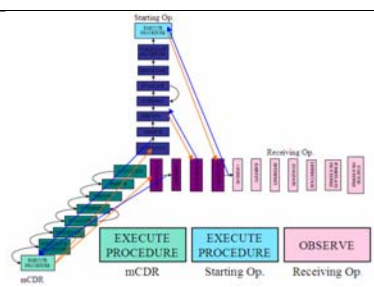
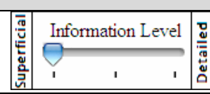
<tr><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td></tr>
<tr><td rowspan="2">

UAV in surveillance state</td>
<td>
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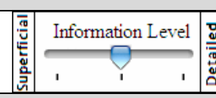
<td>
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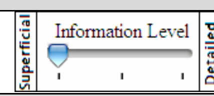
<td>
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<tr><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td><td>- Same set of information from the previous step</td></tr>
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Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

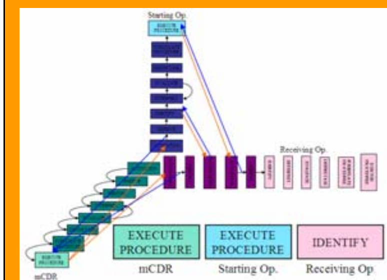
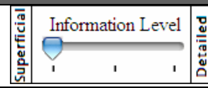
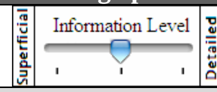
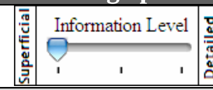
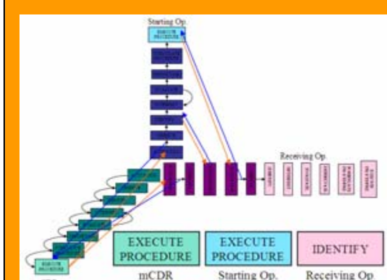
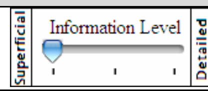
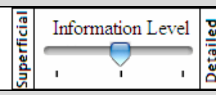
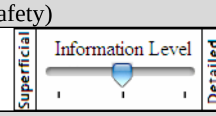
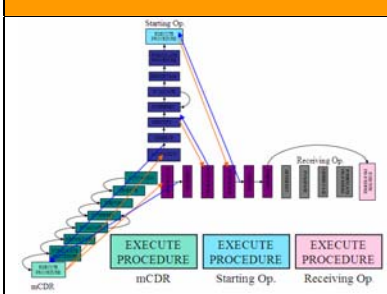
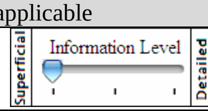
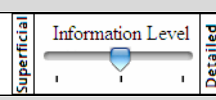
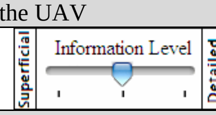
CDPD Step	Mission commander	Starting operator	Receiving operator
 **State Change:** **UAV in non-steady state**	 - ATR off - Activity: Going from surveillance to transiting state - Operator in control of UAV - UAV number - UAV location and estimated time to arrive at receiving op's region (driven from current location and based on chosen route). - Critical information (about fuel, health, connection) if applicable.	 - ATR off Activity: Transitioning from surveillance route to transiting route - Going from low to high altitude (possibility to monitor altitude) - Going from low to high speed (possibility to monitor speed) - Critical status information if applicable - UAV number - UAV location and estimated time to arrive at receiving op's region - Estimated time to enter the range of the target that shot down the UAV - Planned reassignment routes (nominal and safety)	 - Operator in control of UAV - ATR off Activity: Transitioning from surveillance route to transiting route - Going from low to high altitude - Going from low to high speed (possibility to monitor speed) - Critical status information if applicable - UAV number - UAV location and estimated time to arrive at receiving op's region - Estimated time to enter the range of the target that shot down the UAV - Planned reassignment routes (nominal and safety)
 **State Change:** **UAV in transiting state**	 - ATR off - Activity: follow reassignment route ("on route") - Transiting speed and altitude Reassignment route (nominal or safety) - Operator in control of the UAV - UAV number - UAV location and estimated time to arrive at receiving operator's region (driven from current location and based on chosen route). - Critical status information if applicable	 - ATR off Activity: follow reassignment route ("on route") - Transiting speed and altitude - Reassignment route (nominal or safety) - Critical status information if applicable - UAV number - UAV location and estimated time to arrive at receiving operator's region - Estimated time to enter the range of the target that shot down the UAV	 - Operator in control of UAV - ATR off Activity: follow reassignment route ("on route") - Transiting speed & altitude - Reassignment route (nominal or safety) - Critical status information if applicable - UAV number - UAV location and estimated time to arrive at receiving operator's region - Estimated time to enter range of target that shot the UAV
 UAV in transiting state	 - Same set of information from the previous step	 - Same set of information from the previous step	 - Same set of information from the previous step

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

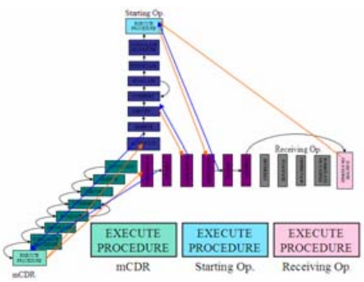
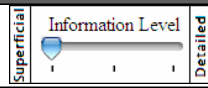
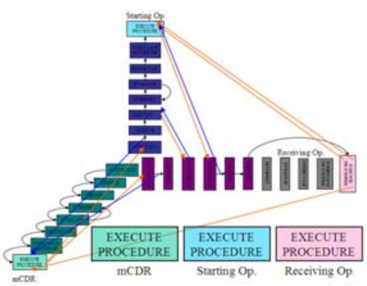
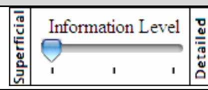
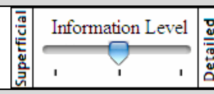
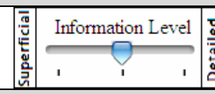
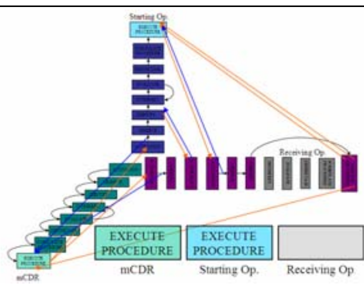
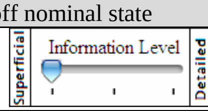
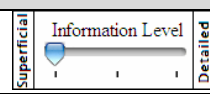
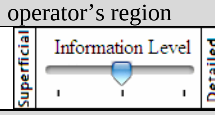
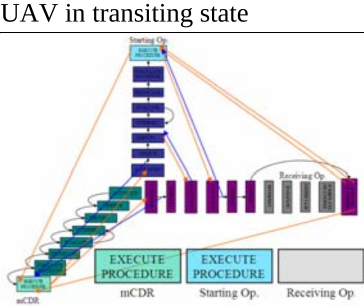
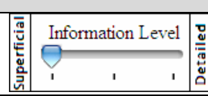
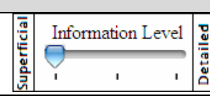
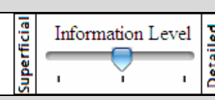
CDPD Step	Mission commander	Starting operator	Receiving operator
 UAV in transiting state	 ATR off - Activity: follow reassignment route - Transiting speed and altitude - Reassignment route (nominal or safety) - Operator in control of UAV - UAV number - UAV location and estimated time to arrive at receiving operator's region - Critical status information if applicable. - Estimated time for change in control of the UAV	 - ATR off - Activity: follow reassignment route - Transiting speed and altitude - Reassignment route (nominal or safety) - Operator in control of UAV - UAV number - UAV location and estimated time to arrive at receiving operator's region - Critical status information if applicable. - Estimated time for change in control of the UAV	 - Same set of information from the previous step
 UAV in transiting state	 ATR off - Activity: follow reassignment route - Transiting speed and altitude - Reassignment route - Operator in control of UAV - UAV number - UAV location & estimated time to arrive at receiving operator's region - Critical status information if off nominal state	 - ATR off Activity: follow reassignment route - Transiting speed and altitude - Reassignment route - Critical status information if off nominal state - UAV number - UAV location and estimated time to arrive at receiving operator's region	 - ATR off Activity: follow reassignment route - Transiting speed and altitude - Reassignment route - Critical status information if off nominal state - UAV number - UAV location and estimated time to arrive at receiving operator's region
 UAV in transiting state	 - Same set of information from the previous step	 - Operator in control of the UAV	 - Same set of information from the previous step
 UAV in transiting state	 - Same set of information from the previous step	 - Same set of information from the previous step	 - Same set of information from the previous step

Table B-5 – Information components and level of detail for the UAV as a boundary object (cont.)

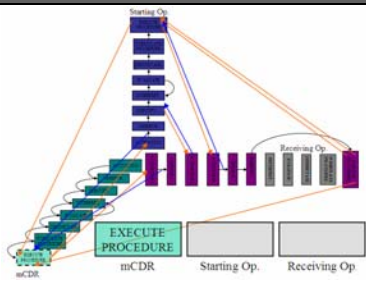
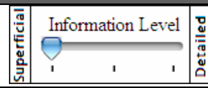
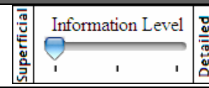
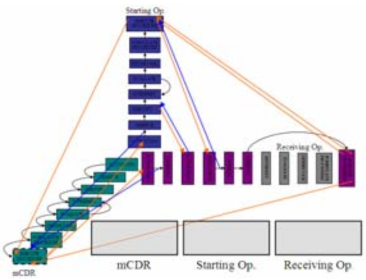
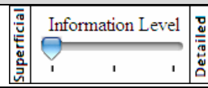
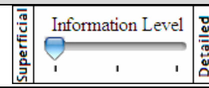
CDPD Step	Mission commander	Starting operator	Receiving operator
 UAV in transiting state			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 UAV in transiting state			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object

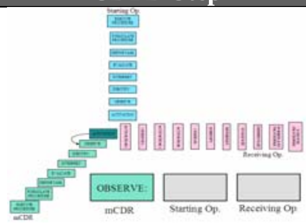
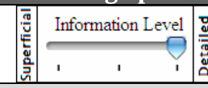
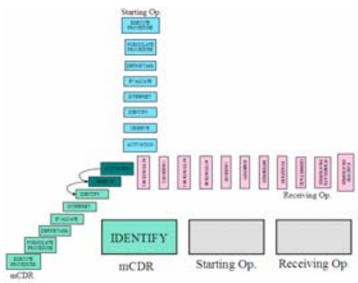
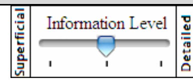
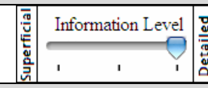
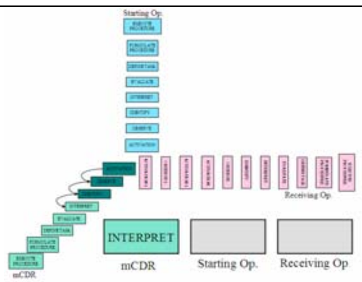
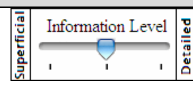
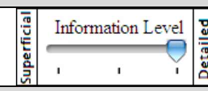
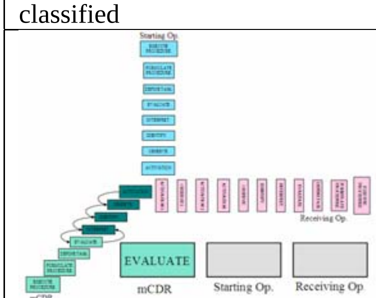
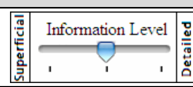
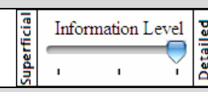
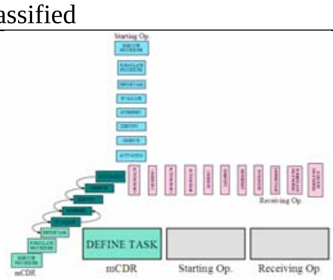
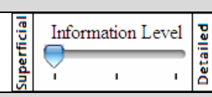
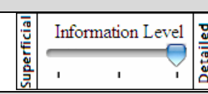
CDPD Step	Mission commander	Starting operator	Receiving operator
 Target State: Discovered but being classified	-	-	
	-	-	- Any information about the target (intell, imagery, ect).
 Target State: Discovered but being classified		-	
	- Threat location and the operator responsible for this region - Elapsed time since target was detected - Team members involved in the threat classification	-	- Same set of information from the previous step
 Target State: Discovered but being classified		-	
	- Same set of information from the previous step	-	- Same set of information from the previous step
 Target State: Discovered but being classified		-	
	- Same set of information from the previous step	-	- Same set of information from the previous step
 Target State: Discovered but being classified		-	
	- Critical delay in target ID - Team members involved in the threat classification	-	- Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object (cont'd)

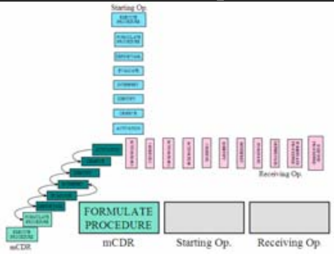
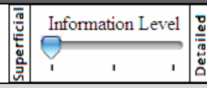
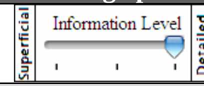
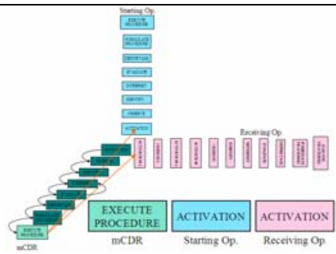
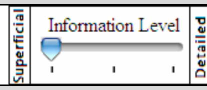
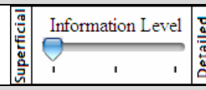
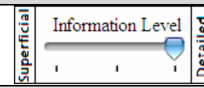
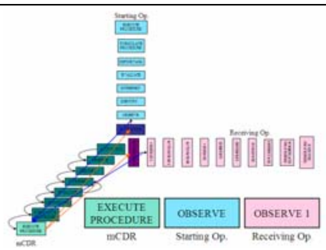
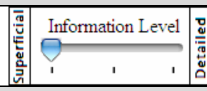
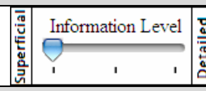
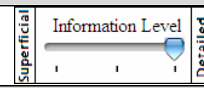
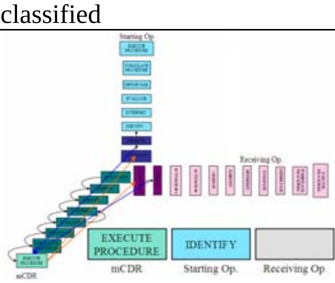
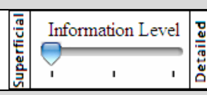
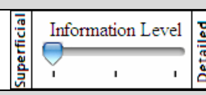
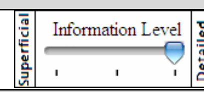
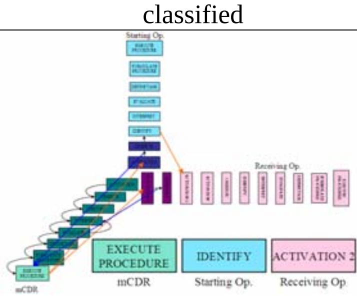
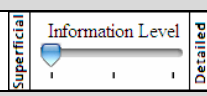
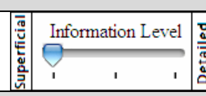
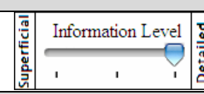
CDPD Step	Mission commander	Starting operator	Receiving operator
 Target State: Discovered but being classified		-	
	- Same set of information from the previous step	-	- Same set of information from the previous step
 Target State: Discovered but being classified			
	- Same set of information from the previous step	- Target location	- Same set of information from the previous step
 Target State: Discovered but being classified			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Target State: Discovered but being classified			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Target State: Discovered but being classified			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object (cont'd)

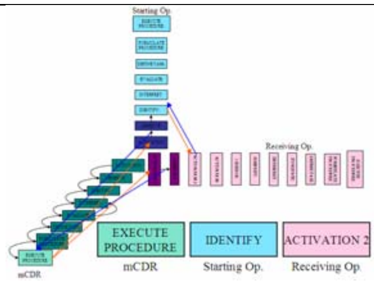
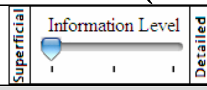
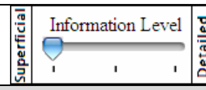
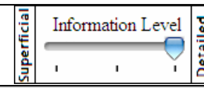
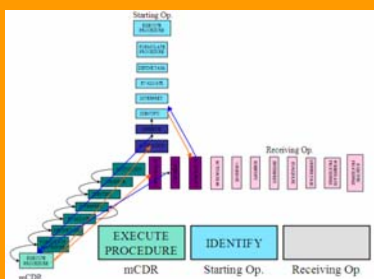
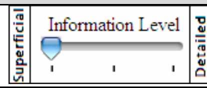
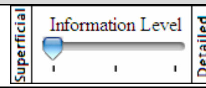
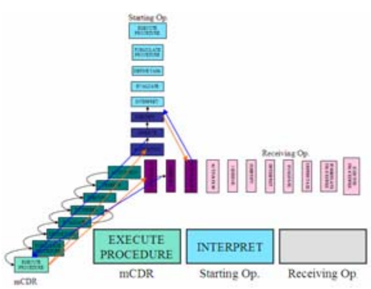
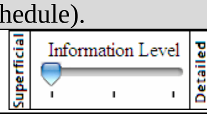
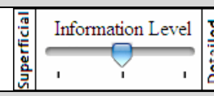
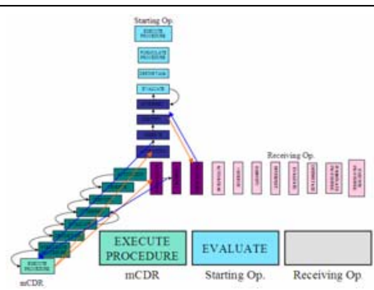
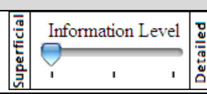
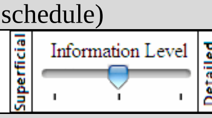
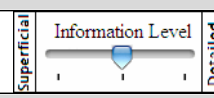
 Target State: Discovered but being classified			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 **State change: Target classified but not scheduled**			
	- Target location - Weapons range (ground) - Elapsed time since info was sent to strike team (show only if it is critical. E.g. if they "never" schedule the target). - Estimated time for the target to be destroyed (based on current and near future strike team schedule).	- Same set of information from the previous step	- Weapons range (aerial) - Target location - Target activity level (aerial) - Estimated time for the target to be destroyed (based on current and near future strike team schedule).
 Target classified but not scheduled			
	- Same set of information from the previous step	- Target location - Weapons range (aerial) - Estimated time for the target to be destroyed (based on current and near future strike team schedule)	- Same set of information from the previous step
 Target classified but not scheduled			
	- Same set of formation from the previous step	- Same set of information from the previous step	- Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object (cont'd)

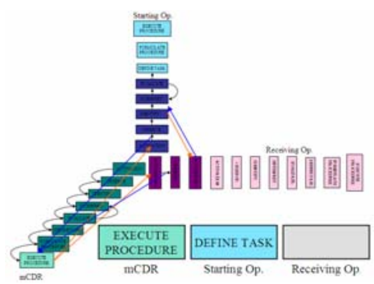
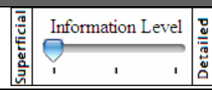
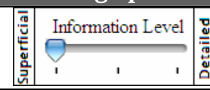
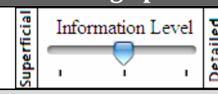
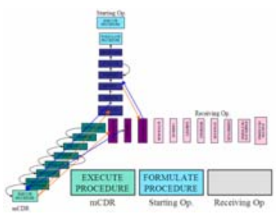
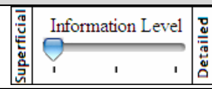
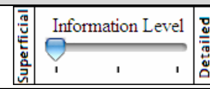
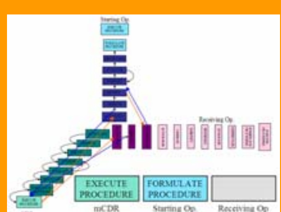
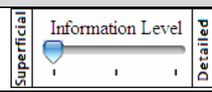
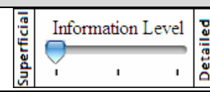
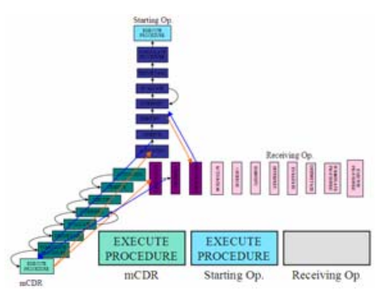
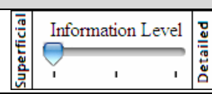
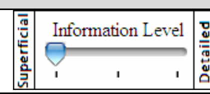
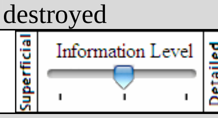
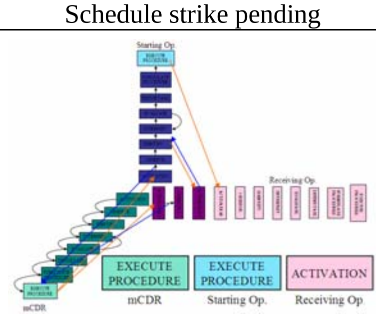
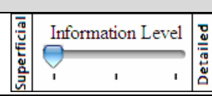
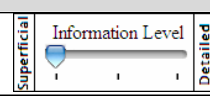
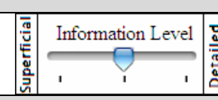
CDPD Step	Mission commander	Starting operator	Receiving operator
 Target classified but not scheduled	 - Same set of formation from the previous step	 - Target location - Estimated time for the target to be destroyed (based on current and near future strike team schedule).	 - Same set of information from the previous step
 Target classified but not scheduled	 - Same set of information from the previous step	 - Same set of information from the previous step	 - Same set of information from the previous step
 State change: Schedule strike pending	 - Target location - Weapons range (ground) - Scheduled time for the target to be destroyed	 - Target location - Scheduled time for the target to be destroyed	 - Weapons range (aerial) - Target location - Target activity level (aerial) - Scheduled time for the target to be destroyed
 Schedule strike pending	 - Same set of information from the previous step	 - Same set of information from the previous step	 - Same set of information from the previous step
 Schedule strike pending	 - Same set of information from the previous step	 - Same set of information from the previous step	 - Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object (cont'd)

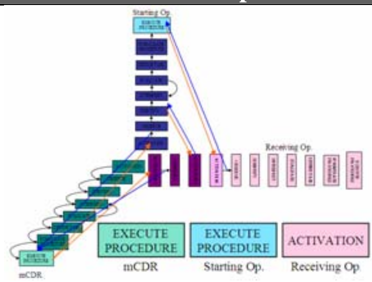
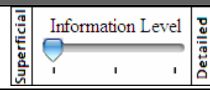
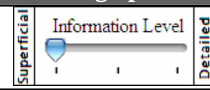
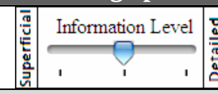
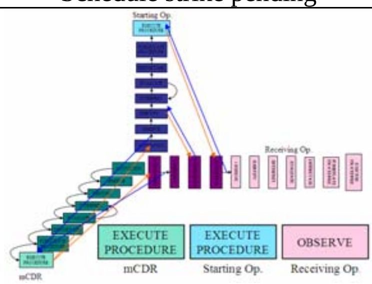
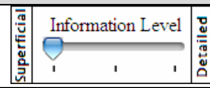
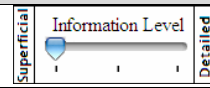
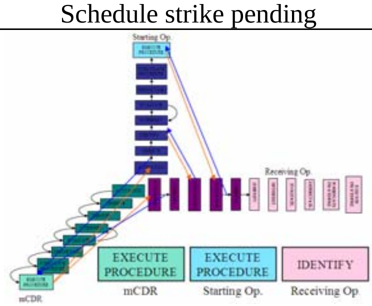
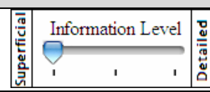
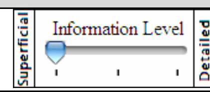
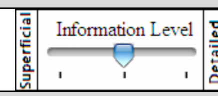
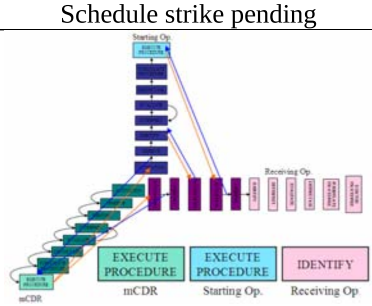
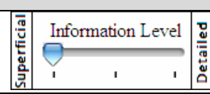
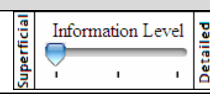
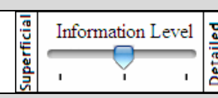
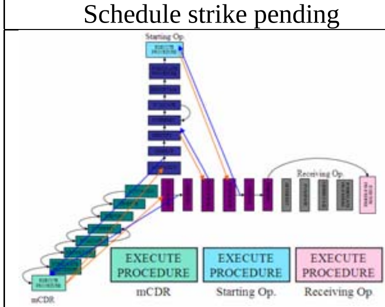
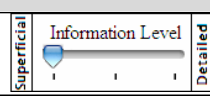
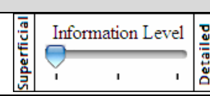
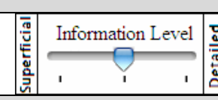
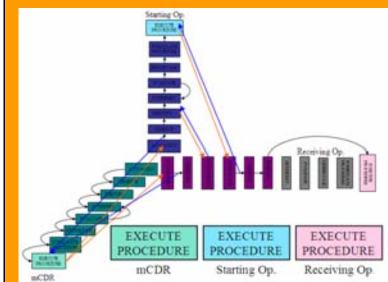
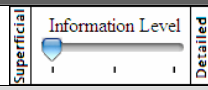
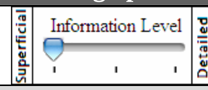
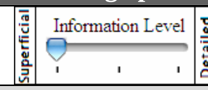
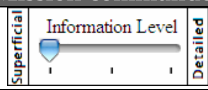
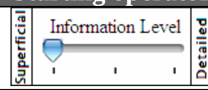
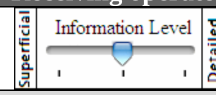
CDPD Step	Mission commander	Starting operator	Receiving operator
 Schedule strike pending			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Schedule strike pending			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Schedule strike pending			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Schedule strike pending			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step
 Schedule strike pending			
	- Same set of information from the previous step	- Same set of information from the previous step	- Same set of information from the previous step

Table B-6 – Information components and level of detail for target (that shot down UAV) as a boundary object (cont'd)

CDPD Step	Mission commander	Starting operator	Receiving operator
			
State change: Target Destroyed	- Destroyed target location	- Destroyed target location	- Destroyed target location

*The target information is no longer relevant to the task after this point.

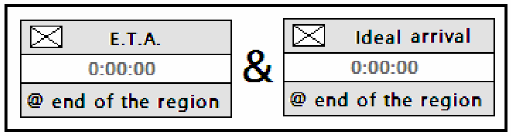
Table B-7 – Information components and level of detail for the convoy as a boundary object
Note: these information components are valid for every step in the CDPD

Mission commander	Starting operator	Receiving operator
		
- Current health status and necessary health to get to the end of the team’s region - Current fuel status and necessary fuel to get to the end of the team’s region - Connection status - Convoy location (in the mission map context) - Convoy location (specific sub-region and correspondent operator) - Estimated time to get to the end of the team’s region - Ideal time for convoy to exit the team’s region - Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV - Estimated loss of health for crossing the threatened region that should have been surveiled by the shot down UAV - Estimated loss of time for stopping the convoy before entering the threatened region that should have been surveiled by the shot down UAV and waiting for the reassignment	- Convoy Location - If starting op is planning routes for the UAV: Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV	- Convoy location - If receiving op is planning handoff time: Estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV

B.5 Information Relationships

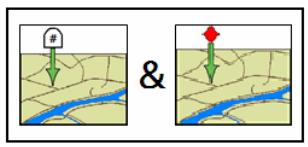
Relationships found among the information provided to the mission commander

1. (**Convoy - Convoy**) The [Estimated time to get to the end of the region] and [Ideal time of arrival at the end of the region] together give measure of the mission overall performance.

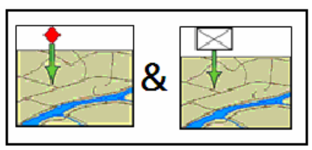


2. (**Target - Convoy - UAV**) Consider the relationships:

(a) [Target location] and [UAV location]

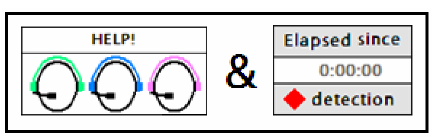


(b) [Target location] and [Convoy location]



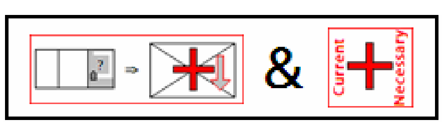
Relationships (a) and (b) together give a qualitative notion of how immediate is the need for the reassignment and/or its feasibility.

3. (**Target - Target**) The [number of team members involved in the target classification] and the [elapsed time since target detection] together give a notion of the difficulty the team is facing to classify the target (an intervention from the mission commander may be necessary).

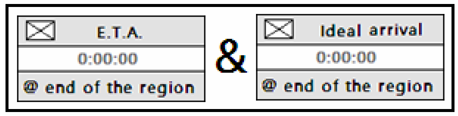


4. (**Convoy - Convoy**) Consider the relationships:

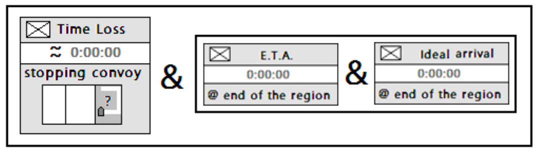
(a) [Current and necessary health to complete the mission] and [estimated loss of health by crossing the threatened area (that should have been surveiled by the shot down UAV)]



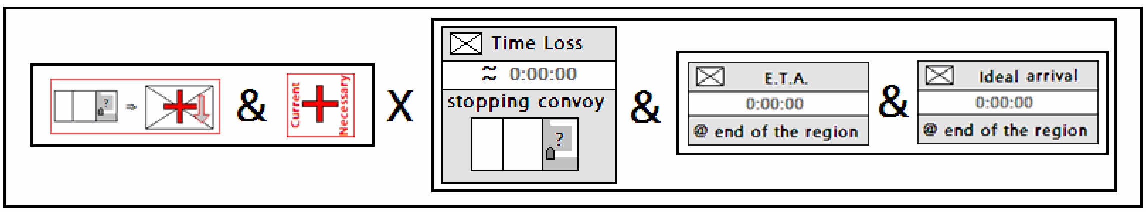
(b) [Estimated time to get to the end of the region] and [Ideal time of arrival at the end of the region] (mission time performance)



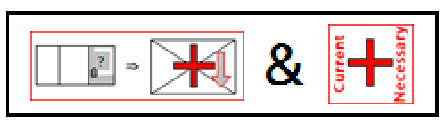
(c) [Estimated time loss for stopping the convoy (waiting for the reassignment)] and [(b)]



[(a)] and [(c)] represent a tradeoff to be analyzed when deciding whether or not to reassign a UAV.

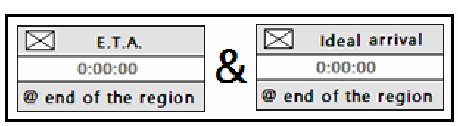


5. (**Convoy - Convoy**) The [current and necessary health to finish the mission] and the [loss of health by crossing the threatened area (that should have been surveiled by the shot down UAV)] together give a notion of the relevance of the health loss, and, consequently, give a possible measure of the relevance of the reassignment.

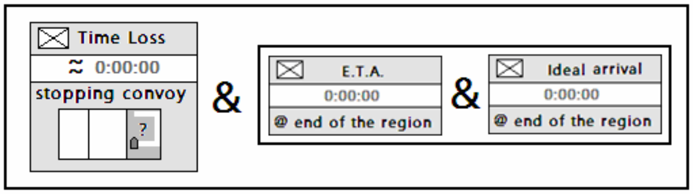


6. (**Convoy - Convoy)** Consider the relationship:

(a) [Estimated time to get to the end of the region] and [Ideal time of arrival at the end of the region]

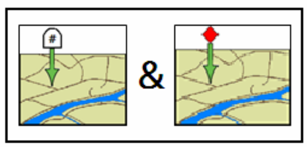


The [time loss by stopping the convoy before entering the threatened region (that should have been surveiled by the shot down UAV)] and [(a)] together give a notion of the relevance of the time loss, and, consequently, may help the mission commander deciding whether to reassign a UAV (and maybe lose some time while waiting for the reassignment) or not (and lose no time, however putting the convoy in danger).



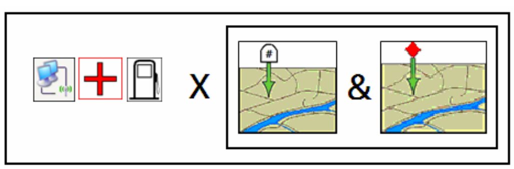
Consider the relationship (valid for the relationships 7, 8, 9 and 10):

(a) [Target location] and [UAV location]



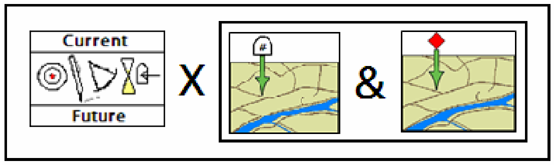
7. (**UAV - (UAV - Target)**) The [current and future UAV activities] and [(a)] together represent a tradeoff to be considered when choosing the UAV to be reassigned.

8. (**UAV – (UAV-Target)**) The [UAV connection, health and fuel status (current and future)] and [(a)] are linked through a compromise relationship: it is ideal to choose the UAV that is closest to the target, however, it is necessary to compare UAVs' limitations for the final UAV choice.

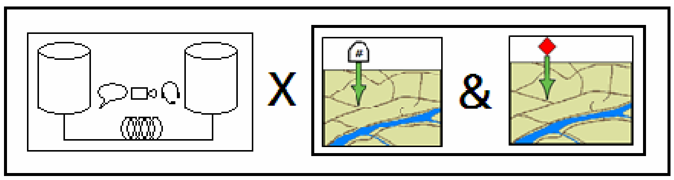


When searching for relationships, we added to the information about the boundary objects some information about the operators involved in the task. We believe this approach will help to explore and represent coordination aspects between team members.

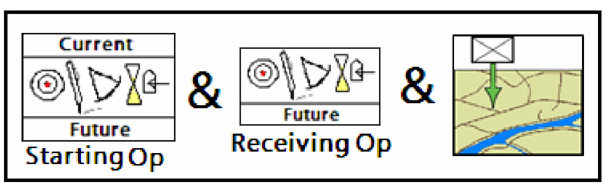
9. (Starting operator – (UAV-Target)) The [Starting operator's current (and expected time of completion) and expected activities] and [(a)] together represent a tradeoff to be considered when choosing the UAV to be reassigned because, although the closest UAV is the ideal for the reassignment, the operator responsible by this UAV may be too busy to handle a reassignment at all.



10. (Starting operator – (UAV-Target)) The [Starting operator available communication options and connectivity of each option] and [(a)] together represent another tradeoff to be considered when choosing the UAV to be reassigned because, although the closest UAV is the ideal for the reassignment, the operator responsible by this UAV may be having problems with communication, which can difficult the information exchange and may compromise the task.

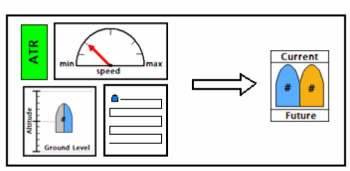


11. (Starting operator – Receiving operator - Convoy) The [Starting operator's current (and expected time of completion) and expected activities] and the [Receiving operator's expected activities] and the [convoy position] all together give a notion of the worthiness of the reassignment. E.g. If the convoy is close to a target that one of the operators (starting or receiving) is supposed to identify, it may be more important to keep the operator in this task instead of having him/her work in a reassignment.

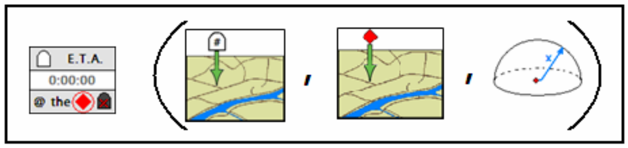


Relationships found among the information provided to the starting operator

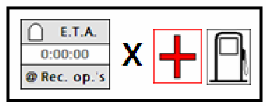
1. (**UAV - UAV**) [ATR on], [low speed], [low altitude] and [surveillance route] are linked to the [UAV activities] in the surveillance state so that the UAV can be efficient in target detection and can acquire high definition imagery.



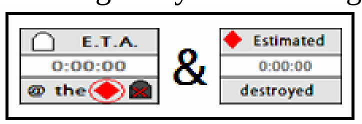
2. (Target - UAV) From the [UAV location], from the [target location] and from the [estimated target range] all together, it is possible to obtain the [estimated time for the UAV to enter the target's range].



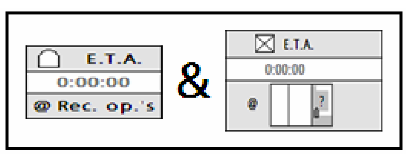
3. (**UAV - UAV**) The [estimated time to arrive at receiving op's region] and the [current and necessary fuel and health] represent a tradeoff to be considered in the routes choice.



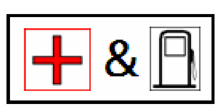
4. (UAV - Target) The [estimated time for the UAV to enter the target's range] and the [estimated time for the target to be destroyed] together can give a notion of the relevance of creating the safety route, or can drive the starting operator to create a nominal route that will result in the UAV entering the target's range only after the target has already been destroyed.



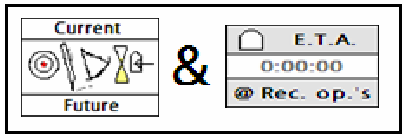
5. (UAV - Convoy) The [estimated time for the UAV to arrive at the receiving operator's region] and the [estimated time for the convoy to arrive at the threatened area that should have been surveiled by the shot down UAV] are related because they give the starting operator the notion of how long should a planned route last (the ideal is that the UAV arrive at the threatened area before the convoy does).



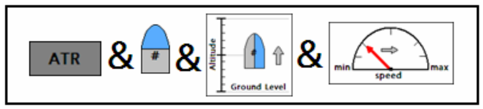
6. The current and necessary [health] and [fuel] are related information because together they allow the starting operator to exclude inconsistent (non-feasible) routes.



7. (UAV – Receiving operator) The [current and expected receiving op's. activities] and the [estimated time for the UAV to arrive at the receiving operator's region] together give a possible approach to estimate an ideal planned route duration. E.g. If the receiving operator will be turning from overwhelmed to available a couple of minutes after the arrival of the UAV in his region, it may be better to choose a route that is a little longer, but that will guarantee that the receiving operator will be able to assume the UAV control. Besides, since the scenario changes with time, it may be the case that the receiving operator gets completely overwhelmed while the starting operator was making the route planning, and in this case, it may be better for the starting operator to ask the mission commander to re-think about the reassignment.

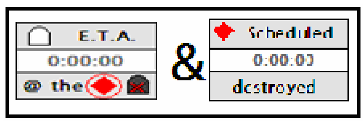


8. (UAV - UAV) The UAV is having its [route], [altitude] and [speed] changed and the [ATR] is off. All these information are related in a way that they characterize the non-steady state.



9. (**UAV - Target**) Consider the relationships:

(a) The [estimated time for the UAV to enter the target's range] and the [scheduled time for the target to be destroyed]

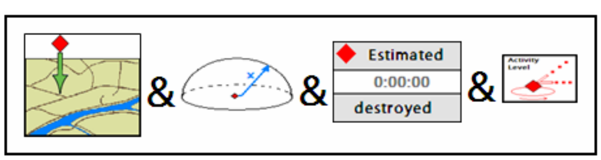


[(a)] is related to the [UAV route: safety or nominal] so that the starting operator may be able to change from safety to nominal route if the strike is scheduled to happen far before the UAV enters the target's range.

10. (UAV - Target) The information about the [target state: destroyed] is related to the [UAV route: safety or nominal] because it allows the starting operator to change from the safety to the nominal route (if he/she has not done that yet).

Relationships found among the information provided to the receiving operator

1. (Target - Target) The [target position], the [target range], the [scheduled time for the target to be destroyed], and the [target level of activity] all together give the receiving operator the notion of how relevant it would be for him/her to do a reroute inside his region before receiving the reassigned UAV (it may be more immediate).



2. (**UAV - Convoy**) The [Estimated time for the convoy to enter the threatened region] and the [estimated time for the UAV to enter the receiving op's region] are related because: if the starting operator could not plan an adequate reassignment route, and the UAV will arrive to late in relation to the convoy in the receiving op's region, the receiving operator can notice that and may do a reroute in his own region before getting the control of the UAV.

The relationships found for the starting operator associated with the monitoring of the reassignment are also valid for the receiving operator after the handoff of the UAV control.

B.6 Summary of Requirements

Table B-8 – Mission commander display requirements summary

<table>
<tr><th colspan="2">Mission commander</th></tr>
<tr><th>Planning Reassignment Task</th><th>Monitoring Reassignment Task</th></tr>
<tr><td colspan="2">TEAM MEMBERS:
- Show operators’ available communication options and connectivity status of each option at basic level
- Show operators’ activities at basic level</td></tr>
<tr><td colspan="2">CONVOY
- Show convoy current health status and necessary health to get to the end of the team’s region (show only if critical) at basic level
- Show convoy current fuel status and necessary fuel to get to the end of the team’s region (show only if critical) at basic level
- Show convoy connection status (show only if critical) at superficial level
- Show convoy location (in the mission map context) at basic level
- Show convoy estimated time to get to the end of the team’s region at basic level
- Show convoy ideal time for convoy to exit the team’s region at medium level of detail
- Show convoy estimated time to reach the potentially threatened region that should have been surveiled by the shot down UAV at basic level
- Show convoy estimated loss of health for crossing the threatened region that should have been surveiled by the shot down UAV at basic level
- Show convoy estimated loss of time for stopping the convoy before entering the threatened region that should have been surveiled by the shot down UAV and waiting for the reassignment at basic level</td></tr>
<tr><td>UAV
- Show shot down UAV location at superficial level
- Show shot down UAV ID info (number, responsible operator, region) at superficial level
- Show UAV current and future activities at basic level
- Show UAV overall fuel and health status (only shown if the UAV is expected to reach some critical level in a near future) at basic level
- Show UAV connection status (only shown if it requires attention, if it is critical) at basic level
- Show operator in control of UAV
- Show UAV number
- Show UAV capabilities at basic level
- Show UAV location at basic level
- Show UAV estimated time to arrive at receiving operator’s region (driven from current location) at basic level</td><td>UAV
- Show UAV current and future activities at superficial level
- Show operator in control of UAV
- Show UAV number
- Show UAV location at low level of detail
- Show UAV estimated time to arrive at receiving operator’s region (driven from current location) at superficial level
- Show critical information (about fuel, health, connection) if applicable at superficial level</td></tr>
<tr><td>TARGET
- Show threat location and the operator responsible for this region at basic level
- Show elapsed time since target was detected at basic level
- Show team members involved in the threat classification at basic level
- Show the target context info (expected time of classification completion and elapsed time) at basic level
- Show critical delay in target ID (if applicable) at basic level
- Show weapons range (ground) at basic level
- Show expected time for the target to be destroyed at basic level
- Show elapsed time since strike schedule request was sent to strike team at basic level
- Show scheduled time for the target to be destroyed at basic level</td><td>TARGET
- Show threat location and the operator responsible for this region at superficial level
- Show elapsed time since target was detected at superficial level
- Show team members involved in the threat classification at superficial level
- Show the target context info (expected time of classification completion and elapsed time) at superficial level
- Show critical delay in target ID (if applicable) at superficial level
- Show weapons range (ground) at superficial level
- Show expected time for the target to be destroyed at superficial level
- Show elapsed time since strike schedule request was sent to strike team at superficial level
- Show scheduled time for the target to be destroyed at superficial level</td></tr>
</table>

Table B-8 – Mission commander display requirements summary (cont.)

<table>
<tr><th colspan="2">Mission commander</th></tr>
<tr><th>Planning Reassignment Task</th><th>Monitoring Reassignment Task</th></tr>
<tr><td>RELATIONSHIPS
- Show [Estimated time to get to the end of the region] and [Ideal time of arrival at the end of the region] and their addition relationship
- Show (a) and (b) and their addition relationship where:
(a) [Target location] and [UAV location] and
(b) [Target location] and [Convoy location]

- Show the [number of team members involved in the target classification] and the [elapsed time since target detection] and their addition relationship</td><td>RELATIONSHIPS
- Show [Estimated time to get to the end of the region] and [Ideal time of arrival at the end of the region] and their addition relationship
- Show the [number of team members involved in the target classification] and the [elapsed time since target detection] and their addition relationship</td></tr>
<tr><th colspan="2">Planning Reassignment Task</th></tr>
<tr><td colspan="2">- Show (c) and (e) and their tradeoff relationship where:
(c) [Convoy current and necessary health to complete the mission] and [convoy estimated loss of health by crossing the threatened area (that should have been surveiled by the shot down UAV)]

(d) [Convoy estimated time to get to the end of the region] and [convoy ideal time of arrival at the end of the region] (mission time performance)
(e) [Estimated time loss by stopping the convoy (waiting for the reassignment)] and [(d)]
- Show the [convoy current and necessary health to finish the mission] and the [convoy loss of health by crossing the threatened area (that should have been surveiled by the shot down UAV)] and their addition relationship

- Show the [time loss by stopping the convoy before entering the threatened region (that should have been surveiled by the shot down UAV)] and [(f)] and their addition relationship where:
(f) [Convoy estimated time to get to the end of the region] and [Convoy ideal time of arrival at the end of the region]

- Show the addition relationship: (g) [Target location] and [UAV location]

- Show the [current and future UAV activities] and [(g)] and their tradeoff relationship

- Show the [UAV connection, health and fuel status (current and future)] and [(g)] and their compromise relationship

- Show the [Starting operator’s current (and expected time of completion) and expected activities] and [(g)] and their tradeoff relationship

- Show the [Starting operator available communication options and connectivity of each option] and [(g)] and their tradeoff relationship

- Show the [Starting operator’s current (and expected time of completion) and expected activities] and the [Receiving operator’s expected activities] and the [convoy position] and their addition relationship

- Show the [estimated time loss for stopping the convoy before entering the threatened region (waiting for the reassignment)] and the dependency it has on the [convoy estimated time of arrival at the threatened region] and on the [UAV estimated time of arrival at the receiving operator’s region]</td></tr>
</table>