INFORMATION ABSTRACTION VISUALIZATION FOR HUMAN-ROBOT INTERACTION

By

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To my beloved and amazing wife, Jennifer

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LIST OF ABBREVIATIONS/NOMENCLATURE/SYMBOLS

10D SART	10-Dimensional Situational Awareness Rating Technique
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosive
CbTA	Constraint-based Task Analysis
CIFA	Cognitive Information Flow Analysis
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DIARE	Decision Information Abstracted to a Relevant Encapsulation
EMS	Emergency Medical Services
EOC	Emergency Operation Center
ES(d)	Cohen's d effect size
ES(g)	Hedges' g effect size
GDTA	Goal-Directed Task Analysis
GOMS	Goals, Operators, Methods, and Selection rules
GVA	General Visualization Abstraction
HAZMat	Hazardous Material
HRI	Human Robot Interface
HTA	Hierarchical Task Analysis
IC	Incident Center
MO	Many at a time and Optional
MR	Many at a time and Required
MRQ	Multiple Resources Questionnaire
OEM	Office of Emergency Management

OO	One at a time and Optional
OR	One at a time and Required
SA	Situational Awareness
SAGAT	Situation Awareness Global Assessment Technique
SD	Standard Deviation
US&R	Urban Search and Rescue
USA	United States of America
UV	Unmanned Vehicle
WDA	Work Domain Analysis

CHAPTER I

INTRODUCTION

This dissertation seeks to inform the development of a system of human-robot interfaces where each interface permits information sharing and visualization at the appropriate abstraction level given users' responsibilities and position in a hierarchical command structure. This dissertation presents the results of two cognitive tasks analyses (CTA) and the integration of the CTA results into the newly proposed Cognitive Information Flow Analysis. These results are the basis for the proposed system of interface visualizations. The primary contribution of this dissertation is the development and evaluation of two visualization techniques; that is, the General Visualization Abstraction (GVA) algorithm and the Decision Information Abstracted to a Relevant Encapsulation (DIARE) objects, which provide integration, abstraction, and sharing of the information generated by the remotely deployed robots.

The response to emergency incidents, including Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) incidents (a.k.a. weapons of mass destruction) is slowly evolving from a response involving humans with equipment to a response system combining humans and incorporating information technology. The response to CBRNE incidents, including all response components (i.e., humans, equipment, and thinking machines) is collectively referred to as the CBRNE response system. The difference between equipment (e.g., fire engines, radios, maps) and thinking machines (e.g., robots, computerized decision support systems) is that machines incorporate some cognitive abilities. If the CBRNE response system is to take effective advantage of emerging technology, the response activity needs to be understood in a way that facilitates the incorporation of these thinking machines and the development of effective human machine interactions. The incorporation of new thinking machines into the CBRNE response system is resulting in a shift, albeit slowly, to a new paradigm.

One method of reaching this new paradigm is to infuse CBRNE incidents with robots that assist with dangerous tasks and extend the life saving resources available to the responders. Several researchers have studied employing or developing robots (i.e., unmanned aerial and ground vehicles) for emergency response including: urban search and rescue (Murphy, 2004; Wegner & Anderson, 2006; Baker, Casey, Keyes, & Yanco, 2004; Yokokohji et al., 2006; Burke, Murphy, Coovert, & Riddle, 2004), natural disasters (Murphy et al., 2008; Murphy & Stover, 2008), emergency incidences (H. Jones & Hinds, 2002; Lundberg, Christensen, & Hedstrom, 2005; Amano, 2002; Lundberg, 2007), CBRNE (Adams, 2005; Humphrey & Adams, 2009a), and wilderness search and rescue (Goodrich et al., 2007, 2008).

The new CBRNE response system that employs robotic technology is considered a semi-revolutionary system. A semi-revolutionary system is similar to a revolutionary system, which is defined as a new system with no existing organizational structure, users, hardware, software, or interface methods (Cummings, 2003; Vicente, 1999). A semi-revolutionary system differs from a revolutionary system in that only some of the hardware, software, interaction methods, organization structure, and users do not exist. In other words, the new system extends or alters portions of the original system, but does not replace the entire original system or represent an entirely new system. The CBRNE response system resulting from the introduction of robotic technologies and visualization methods developed by this research is considered a semi-revolutionary system.

Conducting a Cognitive Task Analysis (CTA) has been shown to assist with developing and introducing new robotic technology by facilitating an understanding of the domain and robot appropriate tasks (Adams, 2005; Almirao, da Silva, Scott, & Cummings, 2007; Goodrich et al., 2008; Adams et al., 2009). Although CTA methods have been conducted for a large number of domains (Endsley, Bolté, & D. G. Jones, 2003; Shepherd, 2000; Vicente, 1999; Yates, 2007), the CBRNE response system presents additional challenges because it is a human based system and involves a significantly broader scope than most systems evaluated with CTA. Most systems analyzed by a CTA technique have one or a few operators using a physical system (e.g., chemical plant). The current CBRNE response system, in contrast, has many "operators" or decision-makers at many different leadership levels and responsibilities. The system is a collection of humans, including decision-makers at various hierarchical levels, and their equipment. The scale of the CBRNE response system can be very large both in terms of geographic dispersion and in terms of the number of people involved in the response system. Considering these challenges, two CTA techniques were chosen: Goal-Directed Task Analysis (GDTA) (Endsley et al., 2003) and Cognitive Work Analysis (CWA) (Vicente, 1999). Furthermore, this dissertation represents the first application of these methods for modeling humans as system components instead of system operators and serves as the basis for all subsequent research in this dissertation.

The Cognitive Information Flow Analysis (CIFA) was developed and applied to the CTA results in order to provide a bridge between the analyses and the design and development of the system of human-robot interfaces. The CIFA focuses on the path of information as it passes through and is transformed by the system at the different User Levels, where User Levels are defined as classes of humans who interact with the proposed robotic system. The CIFA results form part of the basis for the interface visualizations.

There are two purposes in analyzing the CBRNE response system. The first is to understand how the current CBRNE response system operates. The second purpose is to inform the design and implementation of new robotic technology and determine how that new technology will integrate and alter the current system. The first purpose is accomplished by conducting the two CTA techniques: GDTA and CWA. The second purpose has two components: understanding how to inform the design and integrate with the current system, and the implementation of new robotic technology. Informing the system design is accomplished by using the results from the GDTA, CWA, and the CIFA techniques. The implementation of the technology requires developing the robotic hardware and the corresponding human-robot interaction and visualization techniques that allow humans to command, control, and use the resulting robotic derived information (e.g., sensor reading and images).

These proposed CBRNE response system robotic technologies will use computer-based visualizations for both command and control of the robots, and for providing feedback from the robots. This dissertation will focus on two new visualization concepts. The first concept is the General Visualization Abstraction (GVA) algorithm that will appropriately display the most useful information at any given time. The GVA algorithm will employ two primary techniques to abstract the information: filtering and clustering.

The second visualization concept, Decision Information Abstracted to a Relevant Encapsulation (DIARE) objects, is designed to facilitate the sharing of decision-relevant information for particular moments in time with other system users.

In summary, the contributions of this dissertation are as follows. The first contribution is the cognitive task analyses (i.e., the GDTA and CWA techniques) of the human-centric CBRNE response system for the use of incorporating robotic technology. The second contribution is the addition of the extensions to the GDTA and CWA techniques to accommodate a human based system as well as the CBRNE response system scope. The third contribution is the introduction of the CIFA technique to fuse the GDTA and CWA results, provide a different perspective, and assist with designing the CBRNE system and its visualizations. The fourth contribution is the formation of the human-robotic interaction levels for a CBRNE response system, which includes the addition of one new User Level beyond the modifications of Goodrich and Schultz (2007). The fifth contribution is the GVA algorithm framework. The sixth contribution is the DIARE object concept. The final contribution is the implementation and user system evaluation of the two visualization techniques (i.e., GVA algorithm and DIARE concept) for use in CBRNE incidents.

The remainder of this dissertation is arranged as follows: Chapter II provides a literature review, including review of several CTA techniques and a review of visualization techniques related to the GVA algorithm and DIARE concepts. Chapter III presents the methodology and results from the GDTA and CWA techniques. Chapter IV presents the human-robotic user interaction levels. Chapter V presents the CIFA technique including how it compares to GDTA and CWA, and the associated results from the CBRNE response system. Chapter VI presents the GVA algorithm and the DIARE visualization concepts. Chapter VII presents The GVA algorithm user evaluation experiments and results. Chapter VIII presents the DIARE concept user evaluation and results. Chapter IX presents the conclusion and summary of contributions from this dissertation.

CHAPTER II

LITERATURE REVIEW

The CBRNE Response System

This dissertation is designed to apply to the Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE), a.k.a. weapons of mass destruction, response system. The CBRNE response system is the collection of humans (e.g., responders, government officials, civilians), equipment (e.g., protective suits, vehicles, sensors), and, in the future, computing machines (e.g., decision support systems, robotics) that function together as a system to respond to CBRNE incidents. The main difference between general emergency incidents (e.g., fires, hurricanes) and CBRNE incidents is that CBRNE incidents involve serious hazards (e.g., they require protective equipment) and are often deliberate acts with the intention to kill, sicken, and disrupt society ("CBRN," 2008). CBRNE incidents are often acts of asymmetric warfare by terrorist(s) on a civilian population, although occasionally CBRNE incidents are a result of accidents. The CBRNE term denotes the five major hazard types employed in these incidents: chemical, biological, radiological, nuclear, and explosive. CBRNE incidents can range in scale from those that affect a few people in a neighborhood or building, to those that affect millions of people in large regions. CBRNE incidents are infrequent, but have a very long history dating back to at least 1886 in the United States of America (USA) ("List of terrorist incidents," 2008).

The earliest listed CBRNE incident in the USA is Haymarket affair, which turned a rally on May 4^{th} 1886 in Chicago into a riot/massacre because someone threw a bomb at the police (“Haymarket affair,” 2008; “List of terrorist incidents,” 2008). Other recent notable CBRNE incidents in the USA were: the 1984 Rajneeshee bioterror attack (“1984 Rajneeshee bioterror attack,” 2008), the 1993 World Trade Center bombing (“1993 World Trade Center bombing,” 2008), the 1995 Oklahoma City bombing (“Oklahoma City bombing,” 2008), the 2001 September 11 attacks (“September 11, 2001 attacks,” 2008), and the 2001 Anthrax attacks (“2001 anthrax attacks,” 2008). There are many more CBRNE incidents that have occurred both within and outside the USA or that have been thwarted (“List of terrorist incidents,” 2008).

Most of the CBRNE incidents, to-date, have employed explosive hazards (i.e., bombs); however, the potential reach of other hazards is far greater with generally longer lasting health effects, making the need to effectively respond to CBRNE incidents of great importance. Furthermore, every CBRNE incident is different, often dramatically, in part because of different hazards, locations, circumstances, and responding resources. One of the purposes of this dissertation is to facilitate the incorporation of robotic technologies into the CBRNE response system in order to provide more efficient achievement of the three overarching CBRNE response goals.

The *three overarching goals* of any CBRNE incident are life safety, incident stabilization, and property conservation (Shane, 2005). Life safety focuses on minimizing the risk to the responders, ensuring individuals not currently affected by the incident remain safe, and saving as many victim lives as possible. Incident stabilization is the process of containing and mitigating the hazards causing the incident. Property conservation preserves or protects both physical property (e.g., buildings, trees) and commerce (e.g., shipping traffic, customer traffic).

The premise behind incorporating robotic technologies into the CBRNE response system is that the use of robots will improve the life safety goal by extending the range of responders, thereby allowing them to remain safer while possibly locating hazards and victims sooner. The use of robots can improve the incident stabilization goal by providing better diagnostics and monitoring of the situation, thereby allowing the responder to make more informed decisions that can lead to better or quicker incident stabilization. The third overarching goal, property conservation, can be improved as a result of the improvement to the first two goals: the use of robots and their positive impact on life safety and incident stabilization can facilitate a quicker response, thereby reducing the hazard's duration and lingering impact on property and commerce. The incorporation of robotic technologies should not be haphazard, but be the result of a deliberate analysis (Adams, 2002). This deliberate analysis should aim to understand the CBRNE response system both as it is now without robots and as it may be with robots. The type of analysis performed on the CBRNE response system is called Cognitive Task Analysis.

Cognitive Task Analysis Techniques Review

Cognitive Task Analysis (CTA) techniques are designed to elicit knowledge that captures the unobservable cognitive processes, decisions, and judgments that compose expert performance in a system (Yates, 2007). CTA techniques structure this elicited knowledge into models and it is the differences between these models that comprise the different CTA techniques. These techniques are particularly appropriate for analyzing the CBRNE response system because the knowledge captured by CTA techniques (i.e., cognitive processes, decisions, and judgments) is what will be affected by the introduction of new robotic technology. Understanding these effects is important for successful integration of the new robotic technology.

A CTA used for modeling the CBRNE response system must be able to express the interconnectivity of the various CBRNE response system components, express partial orderings of these components, and serve as a guide to developing the resulting command and control of the humans and robots system. There are many CTA techniques (Yates, 2007); however, only the CTA techniques used for systems similar to the CBRNE response system (i.e., complex human machine system) will be discussed.

The concept of Situational Awareness (SA) has been shown to be important in developing human-robotic interaction, especially remote robots, and therefore was represented in the CTA used for the CBRNE response system (Drury, Scholtz, & Yanco, 2003; Scholtz, Antonishek, & Young, 2005; Yanco & Drury, 2004). SA is defined as "the perception of 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" (Endsley, 1988, 1995a; Endsley et al., 2003). The capturing of SA is particularly important for the CBRNE response system because a large percentage of the response system requires perception and comprehension of the environment and its hazards and the projection of hazards' effects into the near future, which map to components of SA (i.e., perception, comprehension, and projection) (Shane, 2005). Therefore, the discussion of the CTA techniques will include how a particular technique does or does not support SA.

Categorizing CTA techniques

The CTA techniques reviewed in this chapter are divided into three categories according to a basic taxonomy. The taxonomy separates the CTA techniques according to their basic modeling focus; that is, whether the technique primarily focuses on modeling goals, or modeling information or data. A CTA technique focused on goals and sub-goals will henceforth be referred to as a *goal-driven cognitive task analysis*, or goal-driven CTA. The second category focuses on the path or flow of the information or data, and henceforth will be referred to as an *information-driven cognitive task analysis*, or information-driven CTA. The third category of CTA techniques is one that combines elements from both the goal-driven and information-driven groups, and is henceforth called *crossover cognitive task analysis*, or crossover CTA. This taxonomy is based on the descriptions and the theoretical framework behind the reviewed CTA techniques and, therefore, is not reclassifying the CTA techniques but is instead designed to add clarity to the presentation of this chapter since a well-established classification system for CTA techniques does not exist (Yates, 2007).

A goal-driven CTA technique is designed to model the overall task by identifying the task goals and subsequently the sub-goals and subtasks that comprise the parent goal or task. This relationship between goals and sub-goals and between tasks and subtasks is called a *part-whole* relationship (Shepherd, 1998, 2000; Vicente, 1999). An analogy for a part-whole relationship is a car: the car is the whole, which is comprised of parts, such as tires. Some goal-driven CTA techniques may have other types of relationships in addition to this relationship, but a part-whole relationship is always present in goal-driven CTA techniques. The information, or data, required to complete a function or goal is not explicitly represented in a goal-driven CTA technique.

An information-driven CTA technique is designed to model a path or paths in which information or knowledge is directed to achieve the overall task. Subtasks can be represented in an information-driven CTA technique, but only in terms of how the functions consume, alter, or create information. Therefore, the relationship between the tasks in an information-driven CTA technique is a *consumer-producer* relationship (Johnston, Hanna, & Millar, 2004). An analogy for a consumer-producer relationship is that in order to write a review paper one must “consume” or read many other papers, which are the products of other writers. Information-driven CTA techniques do not explicitly represent the reasons for executing a task

A crossover CTA technique is one that is either primarily a goal-driven or information-driven CTA technique, which crosses over and represents elements from the other task analysis category. For example, a goal-driven CTA technique that explicitly represents information required by each goal and sub-goals is considered a crossover CTA technique.

Cognitive Work Analysis Decomposed

Before presenting the CTA categorization, it is necessary to first present an overview of Cognitive Work Analysis (CWA), as CWA is not a single method but a collection of methods. According to Vicente (1999), Cognitive Work Analysis is a framework for analyzing human work based on device-independent constraints and contains models of the system independent of any particular worker, control tasks, cognitive task procedures, social-organizational factors, and worker competencies. The purpose of CWA is to assist designers of computer-based information support systems in understanding the socio-technical context in which the workers perform ordinary or unexpected jobs (Vicente, 1999). This section discusses the methods that comprise CWA and how CWA and its methods relate to the three categories of CTA: goal-driven, information-driven and crossover.

Cognitive Work Analysis Methods

Traditional CWA consists of five separate stages: Work Domain Analysis (WDA), Constraint-based Task Analysis (CbTA), analysis of effective strategies, analysis of social and organizational factors, and identification of demands on worker competencies (Vicente, 1999). CWA begins by understanding the environment in which the system is used. As the environment is understood, the analysis transitions its focus from ecological elements to a cognitive analysis to account for the user's actions. Traditional CWA assumes that the system exists and only the human system interaction is being redesigned. However, the CBRNE response system with robotic technology is a *semi-revolutionary* system, a new system that extends or alters components of the original system, but does not replace the entire original system or represent an entirely new system. CWA was extended to revolutionary domains by Cummings (2003) with the introduction of two additional steps: analysis of global social, organizational, and ethical factors, and the creation of a simulated domain. Therefore, modified CWA is believed to be applicable and was used to analyze the CBRNE response system.

Although CWA was initially created for modeling causal systems such as process control plants, it has since been adapted to model various intentional and revolutionary systems. Systems analyzed by CWA that are similar to the CBRNE response system include those in military (Cummings & Guerlain, 2003; Cummings, 2003; Naikar, Pearce, Drumm, & Sanderson, 2003), emergency management (Vicente, 1999), and wilderness search and rescue domains (Adams et al., 2007, 2009). CWA and modified CWA are constraint-based approaches that are intended to provide an overarching framework that yields information and insight even in unanticipated scenarios.

There are seven methods that comprise modified CWA as depicted in Figure 1: analysis of global social, organizational, and ethical factors; Work Domain Analysis; Constraint-based Task Analysis; creation of a Simulated Domain; Analysis of Effective Strategies; Analysis of Social and Organizational Factors; and identifying demands on Worker Competencies (Cummings, 2003).

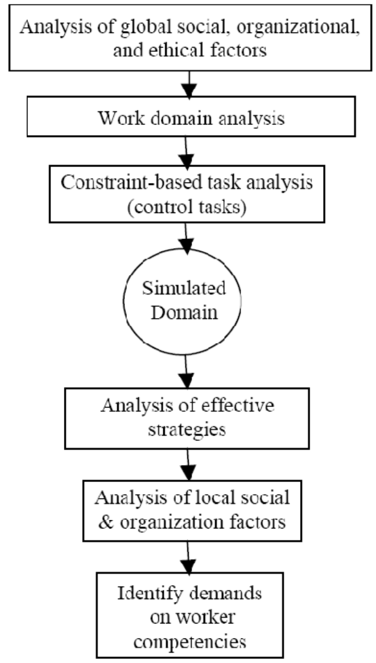


Figure 1: The seven steps of modified Cognitive Work Analysis (Cummings, 2003).

Analysis of global social, organizational, and ethical factors

The analysis of global social, organizational, and ethical factors is designed to foster safer, more effective development of novel technology (Cummings, 2003). The analysis increases the designer's development of a "moral imagination" and an ethical mental model as the system has the ability to affect the welfare and safety of the public (Gorman, Mehalik, & Werhane, 1999). This analysis has three elements: Relevant Social Groups, Communication Flow Map, and Ethical Factors.

Relevant Social Groups identifies stakeholders: those individuals and groups that either influence or are influenced by the system being analyzed (Cummings, 2003). The Communication Flow Map is designed to illustrate how the different social groups communicate with each other and consequently how information is passed between these groups (Cummings, 2003). A Communication Flow Map example, from Cummings (2003), is presented in Figure 2. The Ethical Factors element of the modified CWA is to identify and address possible ethical issues that can arise both in the construction and in the use of the proposed new technological system (Cummings, 2003). The Ethical Factors analysis is critical because the effects and consequences of a decision made with the proposed system can be severe, such as loss of life.

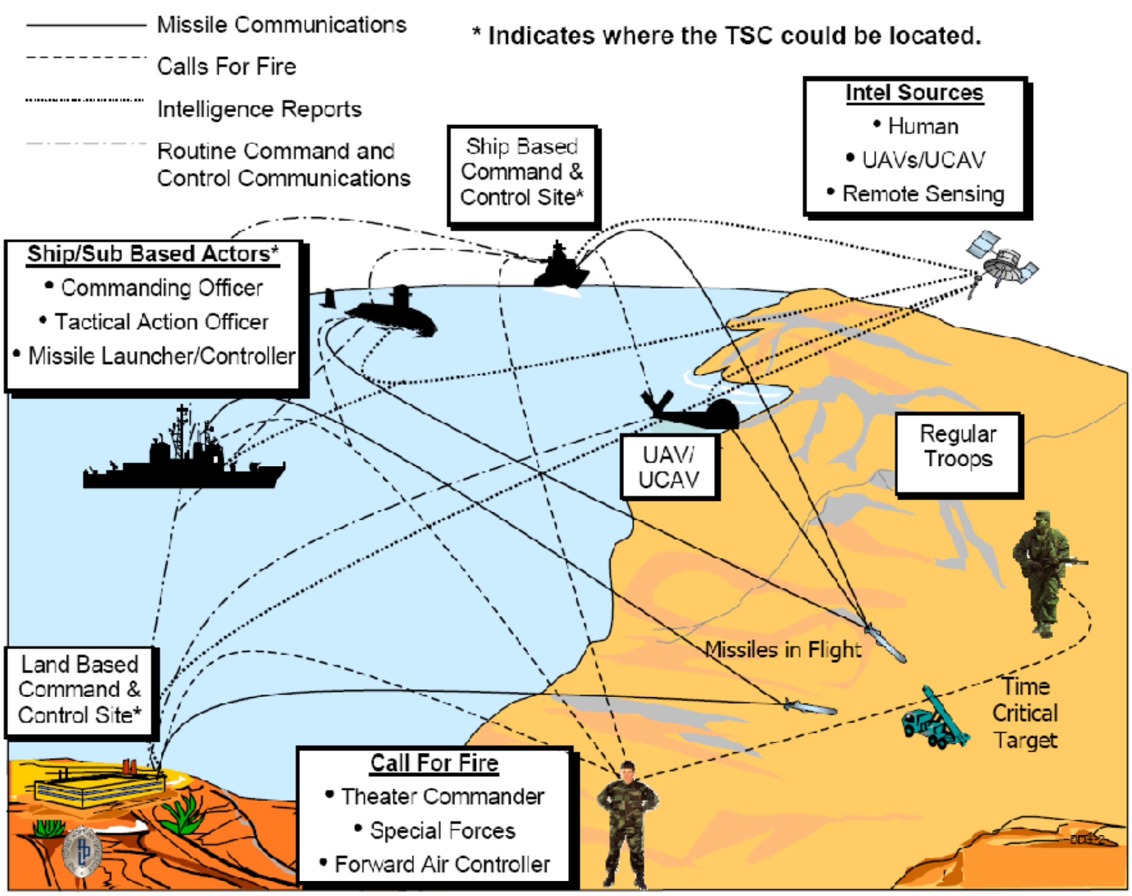


Figure 2: An example of a communication flow map (Cummings, 2003).

Work Domain Analysis and Constraint-based Task Analysis

The CWA's Work Domain Analysis (WDA) focuses on understanding the relationships between subsystems and components (Vicente, 1999). The WDA, by itself, can be considered a CTA technique. The WDA is classifiable as a goal-driven CTA technique and, therefore, is discussed in the goal-driven CTA technique section later in this chapter. The CWA's Constraint-based Task Analysis (CbTA) is designed to model the process of going from decisions to knowledge states as a task is completed (Vicente, 1999). By itself, the CbTA can be considered an information-driven CTA technique and, therefore, is discussed in the information-driven CTA technique section later in this chapter.

Analysis of Effective Strategies, Local Social & Organization Factors, and Worker Competencies

The CWA's Analysis of Effective Strategies is designed to represent the methods by which particular tasks represented in the CbTA can be achieved independent of who is executing the tasks (Vicente, 1999). The CbTA technique focuses on representing the *products* of tasks; whereas, the Analysis of Effective Strategies focuses on representing the *process* of a task.

The CWA component, Analysis of Local Social & Organization Factors, is intended to capture the communication, cooperation, and authority relationships between workers and between other workers and the system. The result describes how tasks can be allocated and how Effective Strategies may be distributed across workers and the system.

The final CWA component, Worker Competencies, is designed to capture the set of constraints associated with the workers themselves, such as capabilities and limitations. The focus of Worker Competencies is to identify the knowledge, rules, and skills that workers should have in order to effectively perform their various functions and responsibilities.

Categorizing Cognitive Work Analysis

As a whole, CWA is classifiable as a crossover CTA technique because its various component methods encompass both goal-driven and Information-driven CTA approaches. The CWA methods, however, are often performed individually (Kaber, Segall, Green, Entzian, & Junginger, 2006; Naikar, Hopcroft, & Moylan, 2005; Vicente, 1999). Individually, only three of the seven CWA methods are CTA techniques; namely, WDA, CbTA, and Analysis of Effective Strategies (Vicente, 1999). The other four methods, by themselves, are not cognitive task analysis techniques as they focus on system aspects other than tasks (Vicente, 1999; Cummings, 2003). Two of the three CWA techniques are discussed in this chapter by themselves as CTA techniques: WDA and CbTA. The Analysis of Effective Strategies is not discussed in the review of CTA techniques because its scope is a single decision and, therefore, it is not designed to model the entire system. The two CWA methods that are discussed in this chapter do not belong to the same CTA group: WDA is a goal-driven CTA technique, and CbTA is an information-driven CTA technique. Part of the appeal of CWA is that the methods analyze the system from different perspectives.

Goal-driven CTA Techniques

Goal-driven CTA techniques are focused on modeling a system's goal and sub-goals through part-whole relationships. Many CTA techniques can be classified as goal-driven (Yates, 2007); however, two techniques have seen widespread use when specifically modeling complex human-machine systems and are, therefore, relevant to modeling the CBRNE response system. The two techniques are the Hierarchical Task Analysis (HTA) (Shepherd, 1998, 2000) and Work Domain Analysis (WDA) (Vicente, 1999). The HTA technique is one of the most common CTA techniques and is based on the concept that task goals and plans can be arranged in a hierarchical fashion (Annett, 2003). The WDA is less common (Jamieson, Miller, Ho, & Vicente, 2007) and is designed to model the constraints of the work domain in which the goals and plans operate (Vicente, 1999). The WDA is, therefore, broader than the HTA in terms of what is included in the analysis.

It must be noted that in Jamieson et al. (2007), the HTA and WDA techniques are not placed in the same group. This dissertation does not dispute Jamieson et al.'s (2007) separation, as the HTA and WDA techniques have distinctly different approaches to modeling the system, which is how Jamieson at al.'s categorization is organized. However, Jamieson et al. (2007) do note that both analyses provide "an understanding of the ways in which known goals can be achieved in various contexts of use," that is, the two techniques are goal-driven, which is how this dissertation has categorized them. Furthermore, both techniques have a part-whole relationship between the elements, another feature of goal-driven CTA techniques.

Goal-Directed Task Analysis (GDTA) (Endsley et al., 2003) and Goals, Operators, Methods, and Selection rules (GOMS) (Card, Moran, & Newell, 1980, 1983) are also goal-driven CTA techniques. The GDTA is designed to identify the users' goals, decisions, and the information needed to support making those decisions (i.e., the Situational Awareness (SA) requirements) (Endsley et al., 2003). The GDTA technique incorporates information that drives how the decisions are made, thus it is classified as a crossover CTA and is discussed in the crossover CTA Technique section later in this chapter. The GOMS technique was established to model a user's procedural knowledge (Kieras, 2003). GOMS has properties similar to HTA (Annett, Duncan, Stammers, & Gray, 1971; Kirwan & Ainsworth, 1992), but the scope is that of a single user's procedural knowledge and renders GOMS very difficult to apply to modeling the entire CBRNE response systems that entails hundreds of users and ill-defined procedural knowledge. Therefore, the GOMS technique will not be discussed further.

Hierarchical Task Analysis Technique

Hierarchical Task Analysis (HTA) has a long history with many variations, extensions, and simplifications (Annett, 2003). The term encompasses ideas developed by Annett and Duncan in the late 1960's and early 1970s (Annett & Duncan, 1967; Annett et al., 1971; Duncan, 1972, 1974). The concept of HTA is to define tasks via a hierarchy of goals and plans, which are composed of subordinate goals and plans. Often, goals at higher levels are more abstract or general, while goals at lower levels resemble tasks or functional steps more directly. However, the actual definition of these nodes and the word “task” itself is somewhat fluid and has seen considerable debate (Shepherd, 1998, 2000).

The HTA technique is a directed graph with a root node and subsequent child nodes linked together by a part-whole relationship. These nodes can represent goals, tasks, plans, and behaviors (Shepherd, 1998, 2000). Regardless of how the nodes are defined, they represent a function that must be completed in order to achieve the objective of the parent node (Figure 3). The sheer flexibility of the HTA technique and its focus on understanding the entire system makes it applicable to the CBRNE response system. Its focus on goals makes it easy to understand and communicate to subject matter experts.

The HTA technique does have a number of limitations in regard to analyzing the CBRNE response system. The HTA technique provides limited mechanisms for scheduling functions, no explicated representation of parallelism, and no information required for decision-making or SA, all of which are vitally important to the CBRNE response system. The HTA provides scheduling only through the introduction of a plan as shown in Figure 3. Figure 3 represents a HTA for the task “Care for and treat babies” from Shepherd (1998) and the plan specified the standard ordering of the functions. The plan is acceptable for one structured execution of tasks; however, if the system is less structured or there are many possible valid execution sequences, then the plan concept becomes very limiting in representing partial scheduling.

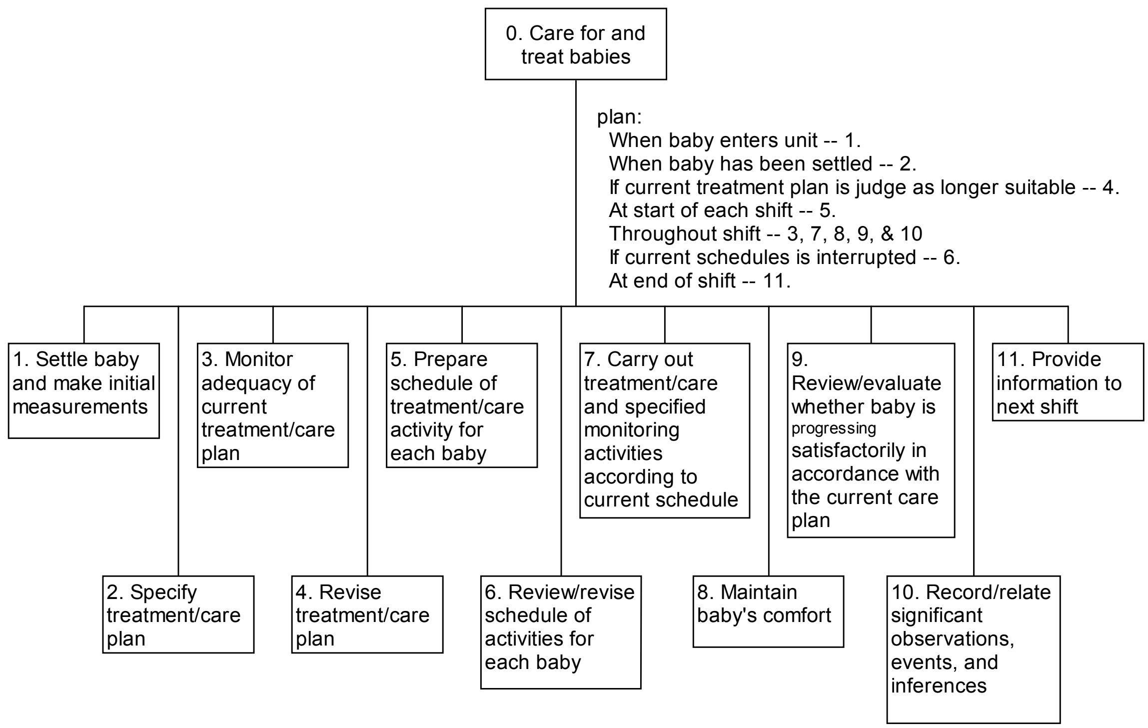


Figure 3: A HTA Example for the Care for and treat babies task from Shepherd (1998).

Work Domain Analysis

One of many components of CWA, the WDA is designed to identify the goal-relevant structure of the system being controlled, independent of any particular worker, automation, event, task, goal, or interface (Vicente, 1999). The WDA has a similar scope as the HTA, that is, the entire domain. The purpose of the WDA is to model the constraints of the work domain in order to create a detailed understanding of the system. The model technique used to perform a WDA has traditionally been an abstraction hierarchy represented as an abstraction-decomposition space, also collectively referred to as an Abstraction-Decomposition (J. Rasmussen, 1985) or simply a WDA (Vicente, 1999). The Abstraction-Decomposition was developed and formalized by Rasmussen over a number of years (J. Rasmussen, 1976, 1985, 1988; Moray, J. Lee, Vicente, B. G. Jones, & J. Rasmussen, 1994) and has been used by many individuals (Cummings, 2003; Krosner, Mitchell, & Govindaraj, 1989; Naikar et al., 2005; Gersh et al., 2005; Lind, 2003).

The Abstraction-Decomposition is similar to HTA; however, the Abstraction-Decomposition has two dimensions that represent different relationships and specified levels of abstraction (as shown in Figure 4). The two dimensions are a means-end relationship along the vertical axis and a part-whole relationship along the horizontal axis. For example in Figure 4, the vertical axis represents the means-end relationships present in the system. The horizontal axis' left most column, in Figure 4, is the whole tactical Tomahawk System and the columns to the right represent components of this system (Cummings, 2003).

The horizontal axis, and therefore the horizontal hierarchy, is in essence a HTA. Where the Abstraction-Decomposition technique differs from, and possibly improves upon, the HTA is in its vertical hierarchy. The vertical hierarchy represents the system through a means-end relationship. The standard five levels, (although five levels are not required) that comprise the vertical hierarchy are functional purpose, abstract functions, generalized functions, physical functions, and physical form (Lind, 1999; J. Rasmussen, 1986). The five levels may also have different labels that essentially represent the same meaning. These alternative labels are goal, priorities measures, general functions, processes, and objects (Cummings, 2003).

	Tactical Tomahawk System	Monitoring Subsystem	Retarget Subsystem	Components
Goal	To support battlefield commanders			
Priority Measuress	• Track strike missiles • Respond to calls for fire/emergent targets	• Accuracy of information	• Missiles redirected as quickly as possible without error • Best possible trade-off decision is made in a retargeting scenario	
General Functions	To monitor and retarget missiles of a Tomahawk strike	Monitor all critical Tomahawk functions and mission data during a strike	Redirect missiles in-fight to either a preprogrammed flex target or an emerging traget	
Processes		• Missile health & status reports, BDI imagery, & transmissions. • Temporal elements • Communications • Spatial attributes of missiles	• Select optimal missile(s) for retargeting • Retarget missiles through both data link and manual entry	• Temporal attributes • Geo-spatial elements • Object information • Communications Data
Objects				• Retargetable Missiles • Loiter Missiles • Emergent Targets • Flex Targets • Waypoints

Figure 4: A WDA example (Cummings, 2003).

The HTA has been compared with the Abstraction-Decomposition (or WDA) (Jamieson et al., 2007; Miller & Vicente, 2001). Although the two techniques have their differences, these differences are complementary (Jamieson et al., 2007). The Abstraction-Decomposition was concluded to provide deeper knowledge and a fuller set of system constraints and capabilities; whereas, the HTA technique was assessed to be a more procedural, human-centered approach that is easily learned and applied (Miller & Vicente, 2001). The Abstraction-Decomposition provides deeper knowledge but the deeper representation, fundamentally, comes at the cost of human readability. This readability may become an issue when interacting with subject matter experts and designers unfamiliar with the Abstraction-Decomposition technique's double hierarchy, as was the case with the CBRNE Response System. Unfortunately, the Abstraction-Decomposition technique, as with the HTA technique, provides no inherent mechanisms for scheduling, representing parallelism, and information required for decision-making or situational awareness.

Information-driven CTA Techniques

Information-driven CTA techniques are focused on modeling a path or paths in which information or knowledge is directed to achieve the overall task. Fewer CTA techniques can be classified as information-driven then can be classified as goal-driven (Yates, 2007). There is one information-driven CTA technique, Constraint-based Task Analysis (CbTA), which has seen use in modeling complex human-machines (Naikar, Moylan, & Pearce, 2006; Vicente, 1999). The CbTA technique is designed to model the process of going from decisions to knowledge states as a task is completed (Vicente, 1999).

Another technique, called the Sensor-Annotated Abstraction Hierarchy (Reising & Sanderson, 2002a, 2002b), is information-driven but may not be classified as a CTA technique because of its focus on the physical system. The Sensor-Annotated Abstraction Hierarchy focuses on a defined set of sensors and not the cognitive processes, decisions, and judgments of the system's users. The Sensor-Annotated Abstraction Hierarchy is not designed to analyze a system composed mostly of humans with an undefined and changing set of information gathering actors (i.e., sensors), as is present in the CBRNE response system. For example, in the CBRNE response system a group of responders will search for victims, but the number of responders and the types of equipment (e.g. sensors) they will have available will vary greatly between and within responses. This mismatch regarding the targeted domain causes the Sensor-Annotated Abstraction Hierarchy technique to be untraceable at this scale and for the CBRNE response system at this time, though it may become relevant in the future. For example, the Sensor-Annotated Abstraction Hierarchy may be used to model the flow of information used by a robot as it performs a task. Figure 5 provides an example of how a Sensor-Annotated Abstraction Hierarchy may represent the flow of information during a visual reconnaissance task for an unmanned helicopter. In this example, the objects represent different low-level physical subsystems (e.g., internal gyro) and as one moves up the abstraction hierarchy the tasks become more complex (e.g., maintain appropriate position).

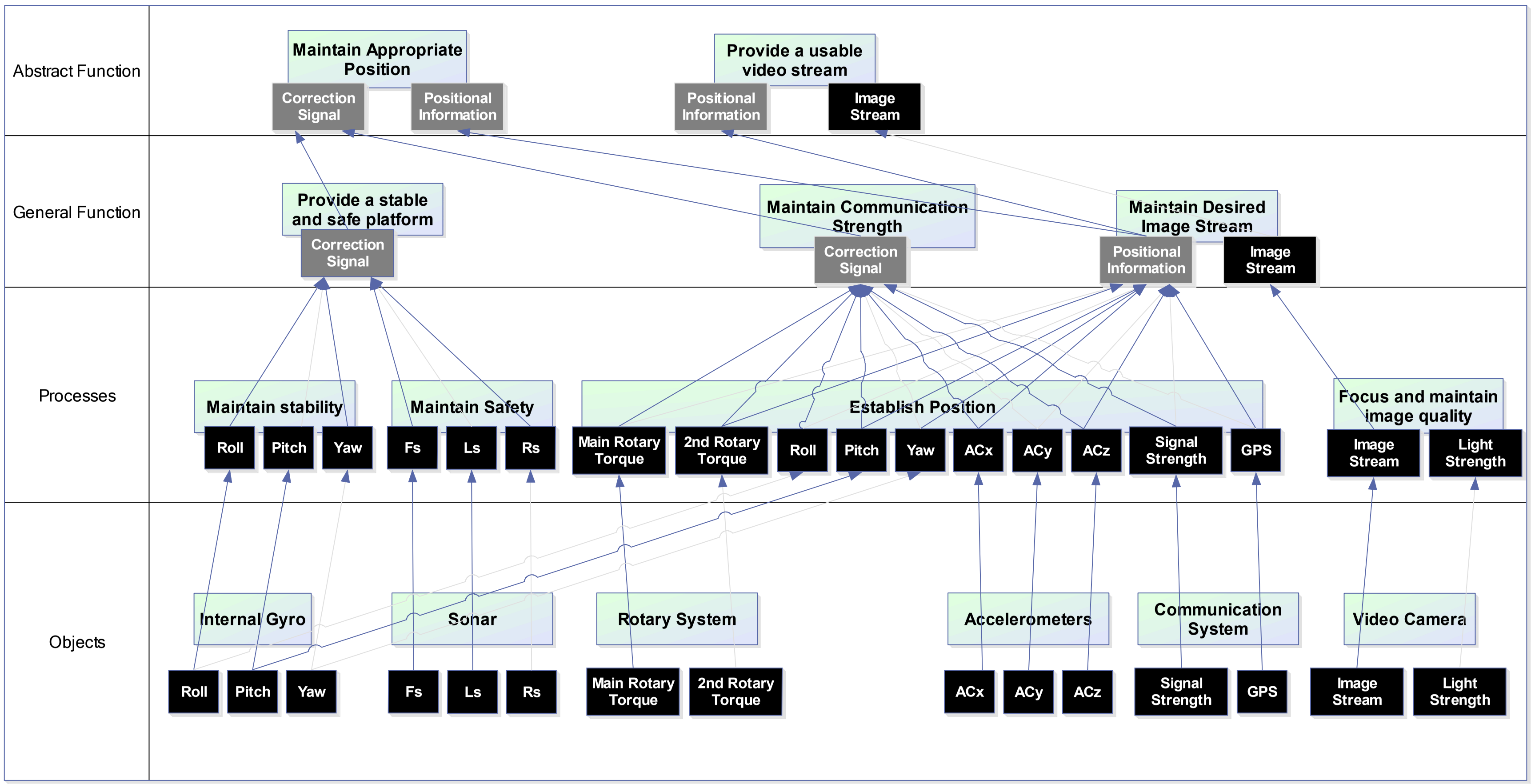


Figure 5: The Sensor-Annotated Abstraction Hierarchy for a hypothetical unmanned helicopter used for visual reconnaissance.

Information-driven CTA techniques are related to the dataflow techniques used in software, signal processing, and embedded system designs (Johnston et al., 2004). Whereas CTA techniques aim to depict the path of information used to make decisions by humans, Visual Dataflow techniques aim to depict the path of information used to make decisions by machines (Diaper, McKearney, & Hurne, 1998). However, as these machines perform more cognitive tasks that were once performed by humans, the distinction between techniques that model human cognitive tasks and those that model machine cognitive tasks diminishes. Therefore, Visual Dataflow techniques are very applicable for representing the path of information for cognitive tasks performed by either humans or machines. Visual Dataflow techniques have also been used as a CTA technique, but such usage is rare (Diaper et al., 1998; Flach, Mulder, & van Paassen, 2004). The Visual Dataflow techniques, although not traditionally viewed as CTA methods, will be reviewed in this section.

Constraint-based Task Analysis

The Constraint-based Task Analysis (CbTA) is an information-driven CTA technique based on a two-step action-knowledge structure. The actions are linked together in an action-means-end relationship (Vicente, 1999). This relationship forms the foundation of the CbTA. The CbTA model provides some mechanisms for the scheduling of actions because of its inherent relationship type and the modeling techniques it traditionally employs.

The traditional modeling language for a CbTA is a Decision Ladder (J. Rasmussen, 1986). The Decision Ladder (DL) is a two-step structure graph based on finite state machines that permit only one state to be active at once. Figure 6 provides an outline of a typical DL reference. The two-step structure is comprised of an information-processing activity node or function node, followed by a state of knowledge node. For example, the function node can be "do homework" and the resulting state of knowledge can then be "homework is finished." The CbTA's Decision Ladder technique only permits one knowledge state or information production from each function node. Decision Ladders' function nodes can be connected to several knowledge states other than the primary proceeding knowledge state (via shunt connections); however, only one of these knowledge states will be entered after the function is performed. Knowledge states can also be connected together through leap connections; however, again only one knowledge state can be active at any given time. A knowledge state may imply that the information items required to do the action are represented in the action node, but it is not explicit. For example, the "homework is finished" knowledge state implies that the function "do homework" took the assignment as an input and produced the homework document as an output information item.

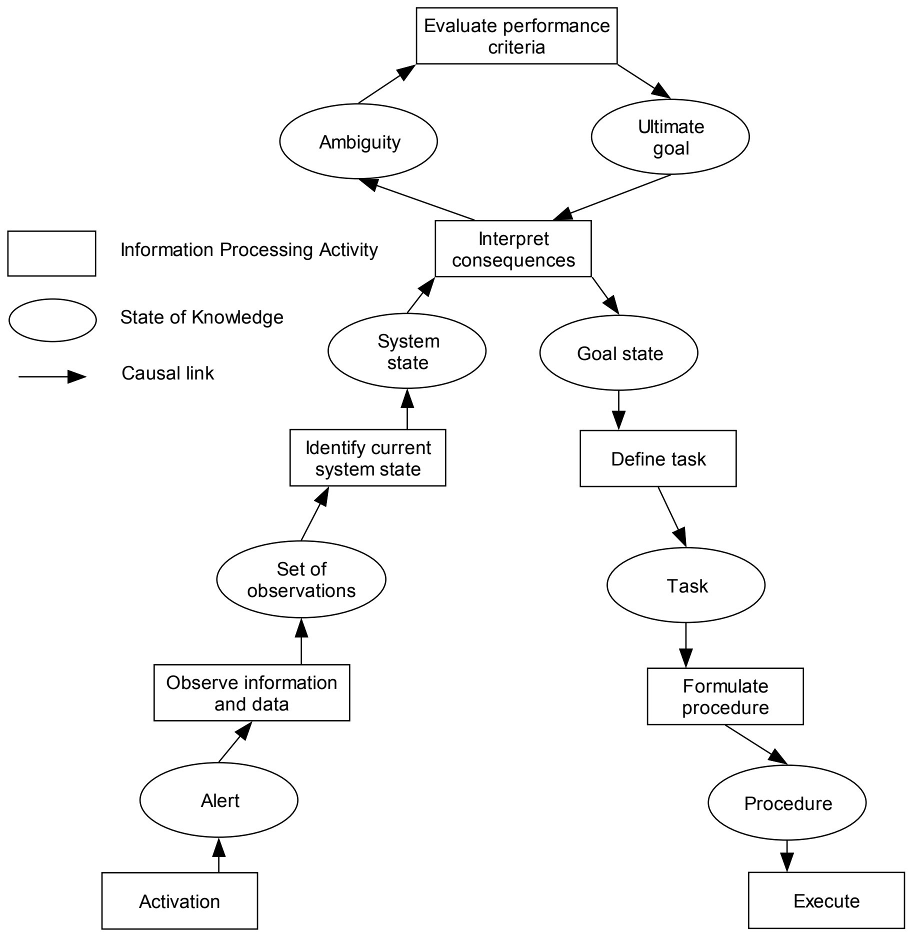


Figure 6: The Decision Ladder (J. Rasmussen, 1976).

The Decision Ladder technique has a number of issues that have caused others to modify or replace it (P. Jones, Patterson, & Goyle, 1993). Decision Ladders are inherently awkward at expressing parallelism or complex partial order scheduling (P. Jones et al., 1993). This awkwardness is a result of Decision Ladders being fundamentally based on finite state machines, which allow only one state to be active at a time. When a Decision Ladder involves more than one decision sequence or the decisions overlap in time, the finite state machine model is inadequate, as it cannot represent parallelism succinctly (Johnston et al., 2004). Jones et al. (1993) extended Decision Ladders for use with two parallel operators; however, this is still inadequate for the

CBRNE response system, as it potentially requires hundreds, if not thousands, of operators.

Visual Dataflow techniques

Although Visual Dataflow techniques are designed to model the decisions made by a system, the basic approach can be applied to modeling cognitive tasks. Indeed, it can be argued that the basic principle enshrined in the Visual Dataflow techniques forms the basis of the CbTA technique. Visual Dataflow techniques are based on dataflow languages.

Dataflow languages were developed in response to the belief that von Neumann processors and their corresponding languages were inherently unsuitable for the deployment of parallelism (Dennis & Misunas, 1974). Dataflow was designed to embrace parallelism by focusing on the data and executing instructions as soon as a function's local data was available. Dataflow imposes a partial ordering constraint on execution, thereby allowing parallelism to be exploited.

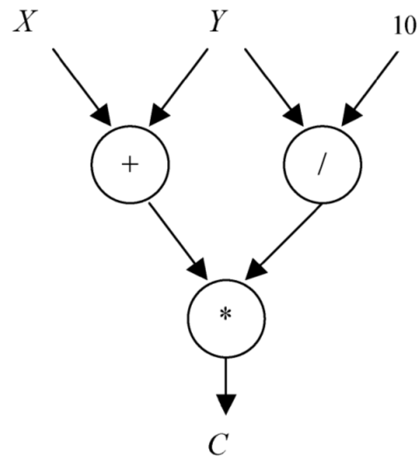
Since the 1990's, dataflow languages have become visual in nature and these newer versions are called Visual Dataflow programming languages (Johnston et al., 2004). The Visual Dataflow programming languages have been refined and developed by a number of individuals over time (see Johnston et al. (2004) for a review). During the development of Visual Dataflow programming languages, the focus slowly shifted from exploiting parallelism to data abstractions due to the advantages that data abstractions provided to the developer during the software development lifecycle (Baroth &

Hartsough, 1995; Johnston et al., 2004). Baroth and Hartsough (1995) reported that developing systems in a Visual Dataflow programming language, namely LabVIEW (2008), was considerably faster, four to ten times faster, than developing systems in procedural functional languages such as C. They attributed the speed improvement to dataflow's ability to show the information processing explicitly and visually. This shift in focus to abstraction and visually representing information processing makes Visual Dataflow an intriguing analysis for modeling the CBRNE system response.

The basic Visual Dataflow technique produces a model that is a directed graph with the nodes representing instructions and the arcs representing the data dependencies between instructions (Dennis, 1974; Johnston et al., 2004) (Figure 7). The data flows on the arcs and conceptually act as data tokens or packages that queue before an instruction in an unbounded first-in, first-out queue (Kahn, 1974). Node execution requires two steps: the first is to wait passively until all required incoming data is present, and then secondly to process the data tokens by placing the output data tokens on all appropriate outgoing data arcs (Dennis, 1974; Johnston et al., 2004). This type of node execution is called *data-availability-driven approach* (Johnston et al., 2004). For example, the result of X + Y in Figure 7 flows as a token on the arc from the "+" to the "*" function nodes and is queued there until Y / 10 produces its token, thereby fulfilling the "*" function node.

$A := X + Y$
$B := Y / 10$
$C := A * B$

(a)



(b)

Figure 7: A simple program (a) and its dataflow equivalent (b) modified from Johnston et al. (2004).

Over time, the expressiveness of the dataflow language has increased so that any arbitrary system can be represented in a dataflow abstraction (Johnston et al., 2004). Much of the work to date has been related to implementing a dataflow language on hardware or maximizing parallelism. Neither of these areas is of interest for the CBRNE response system analysis, as the analysis is intended to guide development and not employed as a pseudo programming language. However, a number of papers and ideas have increased or addressed aspects of dataflow's modeling expressiveness (e.g., how and with what detail level it can model) that will be addressed in the remainder of this section.

Enabling execution control in dataflow models requires the addition of two node types: the SWITCH and the SELECT nodes (Johnston et al., 2004). Both of these nodes perform an if-then-else execution based on an input control signal. The node SWITCH determines which outgoing arc receives the incoming arc's data. The node SELECT determines which incoming arc provides the data to the outgoing arc.

Another extension to the basic dataflow language is the multidimensional dataflow (Murthy & E. Lee, 2002). Multidimensional dataflow addresses the concern that the basic dataflow arcs are modeled after first-in first-out queues, which are inherently one-dimensional. Multidimensional dataflow increases the dataflow expressiveness by transforming the first-in first-out queues into arrays and introduces the concept of queue sampling windows (Murthy & E. Lee, 2002). A queue-sampling window allows the function node to determine its output based on the history of that type of input and not a single sample as in the original dataflow technique. For example, Figure 8 depicts a multidimensional dataflow function node that performs the average operation on an arbitrary length vector, which is something that a standard dataflow cannot express as succinctly. The multidimensional feature is important to the CBRNE response system modeling as most decisions are based on a historical view of the information, which facilitates better quality decisions. For example, in the CBRNE response system, individual hazard readings are transformed into a hazard report not as individual readings, but as a collection. This collection of readings is clearly represented in a multidimensional dataflow concept.

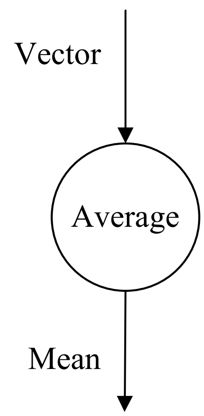


Figure 8: A multidimensional function node that takes a vector of variable length and computes the mean.

The Visual Dataflow technique still has a hierarchical nature, similar to the HTA technique; however, the dataflow hierarchy is determined by the flow of information, not the decomposition of goals or tasks. Therefore, the Visual Dataflow technique does not clearly represent the reason or purpose motivating the existence of each information-processing or function node. Furthermore, the relationship between the information consumed at each node and SA is unclear, in part because the Visual Dataflow technique was not designed to facilitate or consider SA.

Crossover CTA Techniques

CTA techniques that are primarily goal-driven CTA techniques or information-driven CTA techniques that also incorporate aspects of the other analysis techniques are termed crossover CTA techniques. There are very few unified crossover techniques, as there are rarely goal-driven CTA techniques explicitly concerned with information or information-driven CTA techniques that are concerned with goals or decision questions.

A limited number of crossover techniques exist in part because often one will perform a goal-driven CTA and then use the resulting model as the bases for ascertaining information requirements, which are then depicted in tables or lists (Annett, 2003; Miller & Vicente, 2001; Jamieson et al., 2007). Another approach to understanding both goals and information related to a task has been to perform both a goal-driven and an information-driven technique. CWA does this by performing both a WDA and a CbTA (Vicente, 1999); however, it is left to the system designer to relate the results of the two techniques. The pentanalysis technique, like the CWA, also employs both a goal-driven and an information-driven technique, but provides a formal mechanism to relate the results of the two techniques (Diaper et al., 1998). The pentanalysis technique was designed to bridge the gulf between task analysis and data flow analysis (Diaper et al., 1998). The pentanalysis technique essentially employs a special table that relates the task analysis to the data flow analysis.

The hybrid CTA method proposed by Nehme, Scott, Cummings, and Furusho (2006) and extended by Almirao, da Silva, Scott, and Cummings (2007), like CWA, uses several methods to represent both goals and information. The hybrid CTA uses four methods: a scenario task overview, an event flow diagram, a list of situation awareness requirements (i.e., information requirements), and decision ladders (i.e., CbTA). The hybrid CTA employs the scenario task overview and the event flow diagram to represent goals and employs the list of situation awareness requirements and decision ladders to represent information.

The CWA, the pentanalysis technique, and the hybrid CTA do not present their goal-driven and information-driven components in one coherent model. In contrast, the crossover CTA techniques present a unified, explicit representation of both the goals and information in one model. The Goal-Directed Task Analysis (GDTA) technique represents both goals and information in one model and is therefore a crossover CTA technique. The GDTA technique is applicable to systems such as the CBRNE response system (Endsley et al., 2003) in part because GDTA focuses on situational awareness (SA) by representing information requirements, for certain goals, in its goal hierarchy.

Goal-Directed Task Analysis

Endsley et al. (2003) recommend using Goal-Directed Task Analysis (GDTA) for identifying the system's users' goals, decisions, and the information needed to support making those decisions, namely the Situational Awareness (SA) requirements. This method seeks to discover the ideal information the user would like to know in making each decision required to complete each goal. The GDTA technique is therefore not bound to what currently exists, and leaves room to identify potential system improvements (Endsley et al., 2003).

The basic framework of Goal-Directed Task Analysis (GDTA) is a goal-driven CTA where nodes represent goals, decisions, and actions (Endsley et al., 2003). The links between the nodes represent part-whole relationships. The GDTA technique is structurally similar to a HTA, and it inherits much of the HTA technique's flexibility. The GDTA, however, does not use plans, like HTA, and therefore does not represent scheduling or parallelism as succinctly as do the information-driven CTA techniques. The GDTA extends the basic HTA structure with the representation of information requirements and decision questions. The GDTA has been compared to the WDA and has been found to be complementary (Humphrey & Adams, 2009a; Kaber et al., 2006; Adams et al., 2009).

GDTA is considered a crossover CTA because it augments a goal node with information that drives the outcome to that goal. The information represents both the data required to perform the node's goal and the data required to maintain the user's situational awareness (SA) relating to that goal (Endsley, 2001; Endsley et al., 2003). The concept of SA has swayed between being focused almost exclusively on awareness to being more balanced between situation and awareness (Flach et al., 2004). Therefore, each GDTA node represents not only a simple goal, but also a decision, and the information requirements needed to support SA and the decision making process in order to achieve the goal (Flach et al., 2004). Figure 9 depicts an example GDTA with two levels of goals, decision questions, and SA requirements from Kaber et al. (2006).

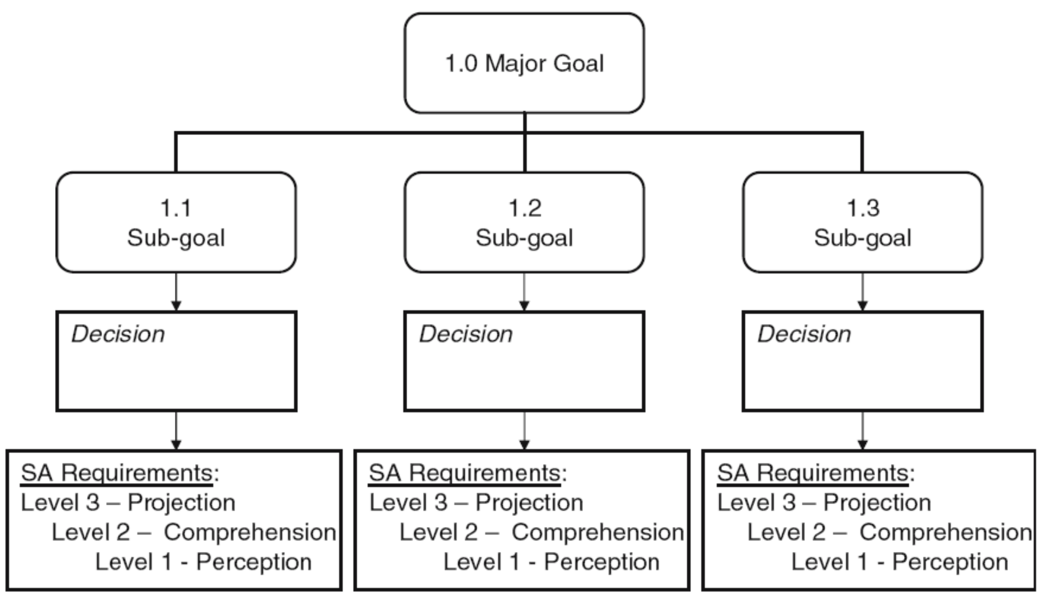


Figure 9: An example GDTA from Kaber et al. (2006).

Flach et al. (2004) extended the GDTA technique by creating levels of information requirements that better address the balance between situation and awareness. The information requirement levels proposed are very similar to the abstraction levels in the WDA abstraction decomposition space. The levels proposed are functional purpose, functional measurement, functional organization, and physical function (Flach et al., 2004). The physical function is defined as the logical decomposition of the information flow through the network of functions. At this information level Flach et al. (2004) borders on incorporating a data flow model into GDTA; in fact, it can be argued that a data flow model is the most appropriate model to express the concepts outlined at the physical function level. The physical function level of the information requirements provides the means of representing a partial order of the information requirements. However, it is unclear whether merely expressing the information requirements with a partial ordering will actually mitigate the overall GDTA's inability to represent scheduling and parallelism.

The GDTA technique produces a model that contains goals, tasks, and information requirements. The GDTA, however, does not represent scheduling and parallelism as do the information-driven CTA techniques. Flach et al.'s (2004) extension mitigates this issue to some extent, but not through one integrated model. The GDTA's ability to represent both goals and information, along with its focus on SA makes it applicable to the CBRNE response system.

Cognitive Task Analysis Techniques Applied to Robotic Systems

A number of CTAs for various aspects related to emergency response exist (e.g., A. C. Jones & McNeese, 2006; Ntuen, Balogun, Boyle, & Turner, 2006); however, these analyses do not focus on robotic systems. A few researchers have applied CTA techniques to analyze robotic systems. The two most common CTA techniques employed have been GDTA and the CWA's WDA. Riley, Murphy, and Endsley (2006) conducted a GDTA on tasks involving an existing urban search and rescue ground based robot. Riley and Endsley (2005) performed a GDTA for a futuristic ground based robot control task involving collaboration between robots in a minefield breach task. Adams et al. (2009) conducted GDTA and CWA for a wilderness search and rescue aerial robot that appears to be the first to inform a real aerial robot system. Rasmussen (1998) conducted a CWA on a command and control information system that utilized aerial robots for suppression of enemy air defense missions. Gonzalez Castro, Pritchett, Bruneau, & Johnson (2007) employed a CWA for developing unmanned vehicle (UV) procedures, functions, and a proposed ground control station. Nehme et al. (2006) and Almirao et al. (2007) have developed a hybrid CTA technique and have employed it for futuristic aerial robotic systems. This hybrid CTA is similar to Cummings modified CWA (2003) but employs fewer and slightly different steps (see Crossover CTA Technique section above). This dissertation is the first to apply CTA methods to the CBRNE response system for the purpose of incorporating robotic technology.

Summary

There are two purposes in analyzing the CBRNE response system. The first is to understand how the current CBRNE response system operates. The second is to inform the design and implementation of new robotic technology along with how the new technology will integrate and alter the current system. Conducting a Cognitive Task Analysis (CTA) has been shown to assist in developing and introducing new robotic technology by facilitating an understanding of the domain and the appropriate robot tasks (Adams, 2005; Almirao et al., 2007; Adams et al., 2009). The previous sections discussed goal-driven, information-driven, and crossover CTA techniques. Each category has both strengths and limitations. Goal-driven CTA techniques, such as HTA and the CWA's WDA, model goals very well and, to a lesser degree, the reasons or decisions driving the goals, but have limited abilities to represent ordering, parallelism, or SA information requirements. Information-driven CTA techniques, such as the CWA's CbTA and Visual Dataflow, model the flow of information and represent both ordering and parallelism; however, these techniques are limited in representing the reasons or decisions driving the path of information or SA information requirements. The crossover CTA technique, GDTA, models goals, the reasons or decisions driving the goals, and SA information requirements; however, GDTA does not represent ordering or parallelism.

The limitations inherent in the discussed CTA techniques led to the use of a combination of techniques to analyze the CBRNE response system. The reasons for choosing the combination of GDTA and CWA, the methodology of applying these techniques, and the results are presented in Chapter III. The results of GDTA and CWA were used to apply a new technique, Cognitive Information Flow Analysis, which is based on the expressive power of Visual Dataflow. Cognitive Information Flow Analysis is presented in Chapter V.

Visualizing the System

The proposed robotic technologies for the CBRNE response system will use computer-based visualizations for both command and control of the robots and feedback from the robot. This section presents literature related to visualizing a system such as the CBRNE response system.

The emergency response incident is evolving from a response involving humans (e.g., first responders, government officials, civilians) with equipment (e.g., protective suits, vehicles, sensors) to a response system combining humans and thinking machines (e.g., robots). These robots may be assigned to the incident response for many reasons: to facilitate response planning, maintain awareness, remove responders from dangerous situations, and allow for immediate site feedback prior to human responder entry (Humphrey & Adams, 2009b). The robots, along with possibly other human-deployed sensors (e.g., wearable computers with sensors (Bonfiglio et al., 2007)), will generate and capture volumes of information that is not communicated or represented in the existing response system. If the new system presents such a volume of real-time information without an evolution in the data management and visualization techniques, it will likely overwhelm decision-makers, resulting in poor understanding (Cai, Sharma, MacEachren, & Brewer, 2006).

One technique for managing and understanding emergency incidents is to use computer-based visualizations to present the captured information to support decision-making. The proposed CBRNE response system visualization is a directable visualization, which is different from dynamic or interactive visualizations. A *dynamic visualization* contains elements that change with time. An *interactive visualization* contains elements that can be directly manipulated, or the information is under full ownership of the user (Jul & George W. Furnas, 1998), meaning that the system cannot change the information autonomously. An interactive visualization by definition changes over time and therefore is also dynamic. A *directable visualization* is a dynamic visualization that does not allow the user to have full ownership of the elements, meaning the user can only specify what the elements should do not what the elements *will* do. Elements in the CBRNE response system visualization are not under full user ownership because the visualization elements are both in the real world and have some level of cognitive abilities (e.g., robots) to choose their own actions. For example, elements that represent robots can accept commands from the user, but the outcome of the commands are uncertain as the robot may encounter any number of problems (e.g., an unknown obstacle). This lack of full ownership in a directable visualization system makes the interaction and visualization more complicated than in an interactive system. The added complication arises because consequences of a command are uncertain and are only revealed as time passes.

The employed visualization needs to be multi-scale, a consequence of modeling a city-scaled event with small-scaled details. *Multi-scale* in this context means that information exists at multiple levels of detail and that these detail levels are not presented all at once (Jul & George W. Furnas, 1998). The multi-scale feature introduces two related concepts: zoom and information scale. *Zoom* means that the level of visualization detail can change in a navigable manner. *Information scale* is the concept that a particular piece of information is not necessarily present at all levels of detail because the information may be too small, too large, or too dense to be presented at a particular level of detail. For example, if the visualization displays the entire state of Tennessee, an individual house is too small to be visible (i.e., the information is smaller than the smallest unit of presentation detail, in this example, a pixel). Sometimes a multi-scale system is called a Zoomable User Interface to highlight the zooming capability over the information scale (Pook, Lecolinet, Vaysseix, & Barillot, 2000).

A CBRNE response system visualization was designed to support incident management and must provide three features: immediacy, relevancy, and sharing (Cai et al., 2006). *Immediacy* is the concept that the system must provide information on-demand, since time is a precious commodity in emergency incidents. *Relevancy* means that the information content and presented form must fit the current needs of the decision-makers. *Sharing* means that the system needs to disseminate information to multiple decision-makers. From these three features arise three problem areas that are a focus of this dissertation. The three problem areas are information abstraction (a combination of immediacy and relevancy), relaying information to different User Levels (sharing), and temporal navigation (a combination of immediacy and relevancy).

Information Abstraction

Information abstraction is intended to reduce visual clutter while conveying more useful and relevant information. Visual clutter occurs when the number of items (i.e., visual density) is greater than the optimal level, and results in performance losses, increased workload, or negative effects on understanding (Woodruff, Landay, & Stonebraker, 1998). Information abstraction is critical to decision making, as in its absence the decision-maker must manually parse out important information and group related information, which are both cognitively demanding tasks (Wickens, J. D. Lee, Liu, & Gordon-Becker, 2003). Furthermore, some information details cannot be represented at a particular scale without abstraction due to screen size limitations (Pook et al., 2000; Woodruff et al., 1998).

The problem is how to abstract information that has spatial (*x, y*), elevation (*e*), temporal (*t*), information scale (*s*), and semantic meaning (*m*) to reduce clutter, thereby providing a relevant visualization for on-demand decision making. Ellis and Dix (2007) identified eleven cluster reduction techniques in three categories: appearance (i.e., sampling, filtering, change point size, change opacity, and clustering); spatial distortion (i.e., point/line displacement, topological distortion, space-filling, pixel-plotting, and dimensional reordering); and temporal (i.e., animation). Systems based on geographic maps generally employ three techniques to reduce clutter: selecting information to present (i.e., sampling and filtering); grouping information together (i.e., point displacement and clustering); and displaying the information with a shape (i.e., space-filling, change point size, and change opacity) (Woodruff et al., 1998; Ellis & Dix, 2007). Others have also focused on selection (Cui, Ward, Rundensteiner, & Yang, 2006; Ellis &

Dix, 2006), grouping (Jul & George W. Furnas, 1998; Ellis & Dix, 2006), and shapes (Cui et al., 2006; Ward, 2002; Humphrey, Gordon, & Adams, 2006). However, existing solutions rely completely on a priori information (Cai et al., 2006; Humphrey et al., 2006; Jul & George W. Furnas, 1998; Ward, 2002), random sampling (Ellis & Dix, 2006), or require complete end user specification (Ernst & Ostrovskii, 2007; Woodruff et al., 1998).

Solutions relying completely on a priori information item knowledge (Cai et al., 2006; Humphrey et al., 2006; Jul & George W. Furnas, 1998; Ward, 2002) use preprogrammed rules to determine the information abstraction, grouping, and presentation. These rules require that the system designer anticipate all possible information that may be encountered and organize it in ways that support decision-making. When systems are deployed in highly dynamic and unpredictable environments (e.g., the CBRNE response system), developing rules for all possibilities is improbable and leads to brittle systems. Therefore, a more flexible information abstraction method applicable to novel information and unanticipated decision-making tasks is required.

Random sampling (Ellis & Dix, 2006) is a solution that relies on no item information and reduces clutter by displaying a random subsection of the available information. While this method reduces clutter, a diverse set of information types can result in a random selection that does not contain elements necessary for a particular decision. Random sampling is an inherently limiting abstraction technique that is most applicable when information item types are homogenous. This is not the case in the CBRNE response system, which may include hundreds of information item types (e.g., robots, responders, contaminants, victims, and vehicles).

Solutions that require the end user to completely specify the information abstraction are not appropriate for real-time critical decision-making systems like the CBRNE response system. These solutions are most appropriate when the end user can afford the time at the beginning of the visualization usage to discover the parameters that will lead to an effective information abstraction. The time at the beginning of a CBRNE response is the most critical (Howe, 2004), and forcing the end user to use that time to deal with the working of the system's visualization instead of making critical life changing decisions is reckless. It is well known that systems that are difficult to use are typically not adopted, thus relying on large amounts of user specification at the start of an incident is not an option. However, this is not to say that any information abstraction solution for the CBRNE response system cannot be controlled or modified by the end user, but that explicit modification of the visualization should be optional and seldom necessary.

Relaying Information to Different User Levels

The sharing of information across users represents the second problem area and focuses on how to relay or share information to different User Levels. *User Levels* have been based on the taxonomy defined by Scholtz (2003), which was extended by Goodrich and Schultz (2007). Six human robot interaction roles were defined: supervisor, operator, mechanic, peer, information consumer, and bystander. Humphrey and Adams (2009a) added one additional User Level: the abstract supervisor as discussed in Chapter IV. Information sharing is a major issue for emergency incident response systems because the decision makers have diverse goals, responsibilities, time requirements, and geographic locations (Cai et al., 2006; Kyng, Nielsen, & Kristensen, 2006; McNeese et al., 2006). The underlying problem is how to share or relay units of information, or *information items*, that have spatial (*x, y*), elevation (*e*), temporal (*t*), information scale (*s*), and semantic meaning (*m*) (i.e., *x*, *y*, *e*, *t*, *s*, *m*) between decision-makers at possibly different User Levels and across time. Methods designed to address this problem include shared space, large-scale displays, shared flags, instant messaging, activity lists, and activity sessions.

Shared space, sometimes called a project workspace or shared workspace, is a visualization system that acts as though all the users are sharing one program and one screen even though the users are distributed geographically in different locations (Cai et al., 2006; Divitini, Farshchian, & Samset, 2004; Stasse et al., 2009; Tomaszewski & MacEachren, 2006). This technique allows every user to see explicitly what every other user is doing; however, the technique has strong limitations. The shared space technique does not allow users to view different areas of the visualization at the same time and only allows users to share information in real time. Shared space works by specifying the six components (*x*, *y*, *e*, *t*, *s*, *m*) as constants for every user, thereby making sharing simple, but inflexible and limiting.

Large-scale displays are a functional equivalent to shared spaces, except that instead of the users being distributed geographically, all users are in one location and the screen is very large in order to accommodate many people viewing it simultaneously (Baudisch, Good, Bellotti, & Schraedley, 2002; Dudfield, Macklin, Fearnley, Simpson, & P. Hall, 2001; Rauschert et al., 2002).

The *shared flags* technique allows users to create new artifacts in the visualization to highlight ideas to be shared (Tomaszewski & MacEachren, 2006). Unlike shared space, the users are allowed to view different visualization areas simultaneously; however, the cost is that other users may be unaware that a flag has been created or how to navigate to a flag in another area of the visualization that differs from their location in the visualization. Another limiting feature is that the flags are only place-markers and do not eloquently or clearly capture the reason or the change of events that led to the flag's creation. Therefore, shared flags do not share directly any of an information element's six components, but instead add new artifacts and leave the users the task of ascertaining the artifact's relationship to the real information entities.

The *instant messaging* technique allows users to write text messages to one another to express ideas (Meissner, Wang, Putz, & Grimmer, 2006). This technique can express any idea and can share all six information components, but only indirectly. The user receiving this shared information must translate and correlate the text messages back into the information entities they represent. This translation, both into text and back again, is slow and can introduce understanding errors and misconceptions. For example, text from one user representing a particular piece of information may be interpreted by another user as a different piece of information if the text is not precise enough.

The *activity list* technique allows users to create new text entries or annotate automatically created entries presented in a list format that represents items on the map (Tomaszewski, 2008). The entries in the list can be organized in a hierarchical fashion such that parent entries can have many child entries. These entries often store location information allowing the user, through some defined behavior (e.g., clicking a button), to center the map on a particular entry. Time is not usually explicitly represented by these entries although the list format may sort entries in chronological order according to when they were added to the system. Furthermore, these entries do not capture a time range and are implicitly constructed such that users will assume all entries present in the list are valid and exist at the present time.

The *activity session* concept creates an artifact to represent a high-level, logical collection of information entities that illustrate an idea or problem (Tomaszewski & MacEachren, 2006). The concept of an activity session discusses sharing at least five information components (*x, y, e, t, and m*), but the mechanisms the authors choose are limiting and do not allow all information components to be directly shared. Tomaszewski and MacEachren (2006) use shared annotations with the ability to "play" these shared annotations in time order as the means to facilitate activity sessions. *Shared annotations* are shared flags that provide extra text (Tomaszewski & MacEachren, 2006). Once again, information is not directly shared, but is indirectly shared through artifacts, thus requiring users to map the artifacts to the related information entities. The artifacts in the activity session, however, do have a timeline.

Temporal Navigation

The last problem area is temporal navigation or how the user will explore time in the CBRNE response system. Navigation through time is often aided with time marks or the highlighting of key frames or time segments (Wickens et al., 2003). A classic example of time marks is the scenes in the scene selection menu on DVDs. Research exists for navigation through time (Dachselt & Weiland, 2006) and this dissertation does not propose a new navigation through time mechanism, but rather a means of creating time marks automatically (see Chapter VI for details).

Summary

This proposed research to develop a CBRNE response system that includes robotic technology will use computer-based visualizations. Those visualizations must provide three features: immediacy, relevancy, and sharing. It must also address three problem areas: information abstraction and presentation, relaying information to different User Levels, and temporal navigation. This dissertation proposes solutions to these three problem areas in Chapter VI.

CHAPTER III

COGNITIVE TASK ANALYSIS RESULTS

Choosing Cognitive Task Analysis Techniques

Conducting a Cognitive Task Analysis (CTA) has been shown to assist in developing and introducing new robotic technology by facilitating an understanding of the domain and the appropriate robot tasks (Adams, 2005; Almirao et al., 2007; Adams et al., 2009). Chapter II discussed three categories of CTA techniques (i.e., goal-driven, information-driven, and crossover) and their respective strengths and weakness. Two CTA techniques were chosen for the analysis of the CBRNE domain to balance their strengths and weakness. The two CTA techniques are Goal-Directed Task Analysis (GDTA) (Endsley et al., 2003) and modified Cognitive Work Analysis (CWA) (Cummings, 2003). The crossover nature and directness of GDTA along with the broad diversity of the CWA methods provide a more specific and insightful CBRNE domain analysis than either method employed alone.

There are several others who have used multiple CTA methods to balance the CTA methods' strengths and weaknesses (e.g., Adams et al. (2009), Jamieson et al. (2007), Kaber et al. (2006), and Miller & Vicente (2001)). However, only Adams et al. (2009) and Kaber et al. (2006) have paired the GDTA and CWA, as this dissertation does. Kaber et al. (2006) employed both GDTA and CWA's Work Domain Analysis

(WDA) for a supervisory control interface design in high-throughput organic compound screening operation. Adams et al. (2009) employed both GDTA and two components of CWA (i.e., WDA and CbTA) to analyze an existing human-based wilderness search and rescue response. Both Kaber et al. (2006) and Adams et al. (2009) found that the two analysis methods complimented each other and the resulting analysis was more complete and useful than analyses conducted by a single technique.

Miller and Vicente (2001) compared hierarchical task analysis (HTA) with WDA and presented the associated advantages and disadvantages. Their findings hold, with two exceptions, when employing GDTA and WDA to the CBRNE analysis in part because GDTA is structurally similar to HTA as discussed in Chapter II. The first exception is that Miller and Vicente concluded that the HTA more easily identified priority, procedural, and temporal constraints than the WDA. In our analysis, the inability to easily identify temporal constraints was a limitation of the GDTA, the WDA, and CbTA when performed in conjunction with Decision Ladders. This led the CBRNE analysis to employ statecharts instead of Decision Ladders for the CbTA (see Chapter III) and to develop and perform the CIFA (see Chapter IV). Secondly, Miller and Vicente (2001) felt that the HTA was not as useful as the WDA for identifying information requirements. This finding may be an artifact of the order in which they conducted the analyses: the WDA prior to the HTA. We have found the GDTA more beneficial for identifying information requirements than the WDA; however, this is hardly surprising knowing that one of the GDTA's focuses is identifying information requirements.

The two chosen CTA techniques used to analyze the CBRNE domain span all three CTA categories as the CWA's WDA is a goal-driven CTA, CWA's Constraint-based Task Analysis (CbTA) is an information-driven CTA, and the GDTA is a crossover CTA. This chapter discusses the GDTA and CWA results, including any changes made to these techniques in applying them to the CBRNE response system.

People as System Components

The CTA presented in this dissertation treats the human responders in the CBRNE response system as system components. There is some precedence for considering people as system components as Adams et al. (2009) conducted a CTA with the same perspective. Traditional task analysis views the humans as operators or monitors and the system components as being purely physical (e.g., water tank, missile). The human responders in the CBRNE response system and their associated tasks and activities are more akin to elements in the system rather than operators or monitors of the system. In the CBRNE response system, it became essential to view human responders (e.g., a HAZMAT team) as system components. Viewing human responders as system components is essential because the CBRNE response system is almost entirely comprised of human responders, unlike, for example, a chemical plant that has a physical system. However, this perspective does not imply that all people are considered system components. Just as it is with the chemical plant, there are individuals who direct the CBRNE response system and are, therefore, not viewed as system components.

Methodology

The GDTA and CWA results have been developed over three years and the models presented in this chapter and in the appendix represent many hours of research. A preliminary CBRNE response system analysis was constructed using GDTA and CWA based on a collection of documents relating to CBRNE or incident management (Coast Guard, 2006; District 5, 2005; FEMA, n.d.; Shane, 2005; Office for Domestic Preparedness, 2003; US Army Corps of Engineers, n.d.; Howe, 2004, 2005; Homeland Security, n.d.; FEMA, 2005; LaTourrette, Chan, Brower, Medby, & McMahon, 2006; NDOJ, 2005; Peterson, 2002; Ridge, 2003a, 2003b). Subject matter experts included members of the Nashville bomb squad, law enforcement, HAZMAT, SWAT, incident command, fire department, public health, Emergency Medical Services (EMS); Tennessee Bureau of Investigation; The Nashville Mayor's Office of Emergency Management (OEM); the local FBI field office; and the 45th Weapons of Mass Destruction Civil Support Team.

The GDTA model was constructed first and its development always preceded the development of the CWA. The initial GDTA was based on the document review and was repeatedly presented to subject matter experts and revised. An initial WDA was subsequently presented to a few subject matter experts; however, the WDA was much more difficult to communicate to the subject matter experts and resulted in very poor feedback in comparison to the GDTA. Therefore, in addition to the interviews regarding the WDA, the feedback from the GDTA and the interviews in general drove both the GDTA and the CWA development. As the GDTA was refined, so was the CWAAfter the first rounds of document review, interviews, GDTA and CWA development, and subject matter expert review, several exercises were witnessed. Tabletop exercises focusing on chemical CBRNE incidents were attended in Knoxville, TN and Franklin, TN. Several full scale exercises conducted by the 45th Weapons of Mass Destruction Civil Support

Team stationed in Smyrna, TN were observed. A large scale, multiple day, full-scale exercise conducted by the Greater Nashville Homeland Security District 5 was also observed in 2005. These exercises provided new insight into the CBRNE response system and motivated many changes in both the GDTA and CWA as well as another round of subject matter expert interviews.

A scenario was adapted from the Greater Nashville Homeland Security District 5 2005 exercise to facilitate an additional round of subject matter expert interviews for analysis validation purposes. The scenario provided an example incident that allowed the subject matter experts to respond and discuss their insights in a more structured but natural manner than general interviews and GDTA reviews. Using an example to connect to subject matter experts is a well-established procedure that yields good results (Wickens et al., 2003). The review of the scenario provided the last round of subject matter expert reviews.

The entire scenario text was then extended to represent how, hypothetically, robots can be employed and what contributions those robots can provide. This scenario is included in its entirety in Appendix D. A short excerpt from the original scenario text is presented to facilitate a discussion of the GDTA and CWA results. The GDTA and CWA results are then subsequently presented, followed by the same short excerpt scenario, but this time *with* robots and the robots' hypothetical contributions.

The Emergency Evaluation Example

The CBRNE response system encompasses many government agencies, organizations, and responsibilities. The first pass analysis represented the entire response and later efforts focused on areas identified as most appropriate for potential robotic technology. Presenting the entire CTA results in this chapter would be tedious; therefore, this chapter focuses on a particular subset of the CBRNE response system when discussing the detailed results of the CTA techniques. The complete CTA results are provided in

Appendix A and Appendix B. The presented example is based on the CBRNE domain responsibility of Emergency Evaluation. The following scenario text is taken from the Greater Nashville Homeland Security District 5 2005 Emergency Preparedness Challenge Exercise: Controller/Evaluator Handbook (District 5, 2005) and it provides an example of the emergency evaluation activities without robots.

> At 1:00pm, the TN Tower (State Building) explodes.
>
> At 1:01pm, multiple 911 calls are received in the Emergency Communications Center reporting explosions at the TN Tower building. Some calls report that the TN Tower was bombed.
>
> At 1:03pm, building security personnel are reporting massive amounts of casualties and fatalities on scene.
>
> At 1:05pm, First Responders begin to arrive at the scene and report there has been an explosion at the TN Tower. The west side of the TN Tower has been torn off and has collapsed into the building about 150 feet wide and 100 feet into the building and upwards of approximately 300 feet. Several small fires and a damaged portion of the TN Tower have been reported. People are walking around dazed, confused, and bleeding. There are bodies and body parts visible lying on the ground. The debris in the street is slowing down responders.
>
> At 1:07pm, The ECC's Field Incident Response Situation Team (FIRST) deploys to the scene and takes over all tasks normally handled within the center, including notifications and requests for additional resources. The ECC begins to backfill fire halls and perform medical move ups to provide coverage for the remainder of the City. The MCI plan is activated and notifications are made.
>
> At 1:08 pm, Additional First responders arrive on scene to find many Good Samaritans are on the collapsed structure trying to help. Good Samaritans are knocking over debris and falling down while walking and shifting the debris. (District 5, 2005)

This scenario appears to be a bomb incident and it is in these early moments when the Emergency Evaluation activities begin. The goal of the Emergency Evaluation activities is to assess the hazards so that the rest of the CBRNE response system understands the nature of the threat(s) and can respond and perform responsibilities appropriately. This is exactly what starts happening at 1:05pm in the scenario, which is when the First Responders began to arrive and then they immediately started reporting the nature of the hazards at the scene.

Goal-Directed Task Analysis

Methodology

The GDTA technique, in practice, has four primary stages: development of a goal hierarchy, conducting of interviews, development of the expanded goal-decision-SA structure, and obtaining of feedback. The goal hierarchy is a visual structure defining the primary and secondary system goals. Its development included an exhaustive document review, personal contact, free-flowing interviews with subject matter experts, and observation of the current system. Structured interviews with subject matter experts were conducted in order to confirm and modify the initial goal hierarchy. Once the interview results were incorporated into the goal hierarchy, the expanded goal-decision-SA structures were developed by adding additional sub-goal levels in order to obtain the desired detail level. Extensive feedback from subject matter experts regarding SA requirements refined the GDTA into a meaningful sketch of the CBRNE domain with an acute focus on the information required to make ideal decisions.

Goal Hierarchy

The first step in analyzing the CBRNE response system was to review literature, manuals, procedural documents, and reports regarding the system's operation. The primary document source was the Department of Homeland Security. A division of tasks/goals was found in the *Planning Scenarios Executive Summaries* (Howe, 2004, 2005). The document provided a means to divide high-level tasks into different categories, each with a primary goal that was a logical starting point for the goal hierarchy.

Additional scenarios and other related documents were employed to develop the preliminary goal hierarchy and preliminary SA requirements (Coast Guard, 2006; District 5, 2005; FEMA, n.d.; Shane, 2005; Office for Domestic Preparedness, 2003; US Army Corps of Engineers, n.d.; FEMA, 2005; Homeland Security, n.d.). After several subject matter expert interview and revision cycles, the post-interview goal hierarchy was finalized and is displayed in Figure 10.

The goal hierarchy, as shown in Figure 10, begins with the main CBRNE response goal of "Life Safety, Incident Stabilization, and Property Conservation," which is the concatenation of the three overarching goals of the CBRNE response system, as discussed in Chapter II. The next level goals are: "Prevention/Deterrence," "Emergency Evaluation," "Emergency Management," "Incident/Hazard Mitigation," "Victim Care," "Public Protection," "Investigation/Apprehension," and "Recovery/Remediation." These goals are further decomposed into tasks and information requirements.

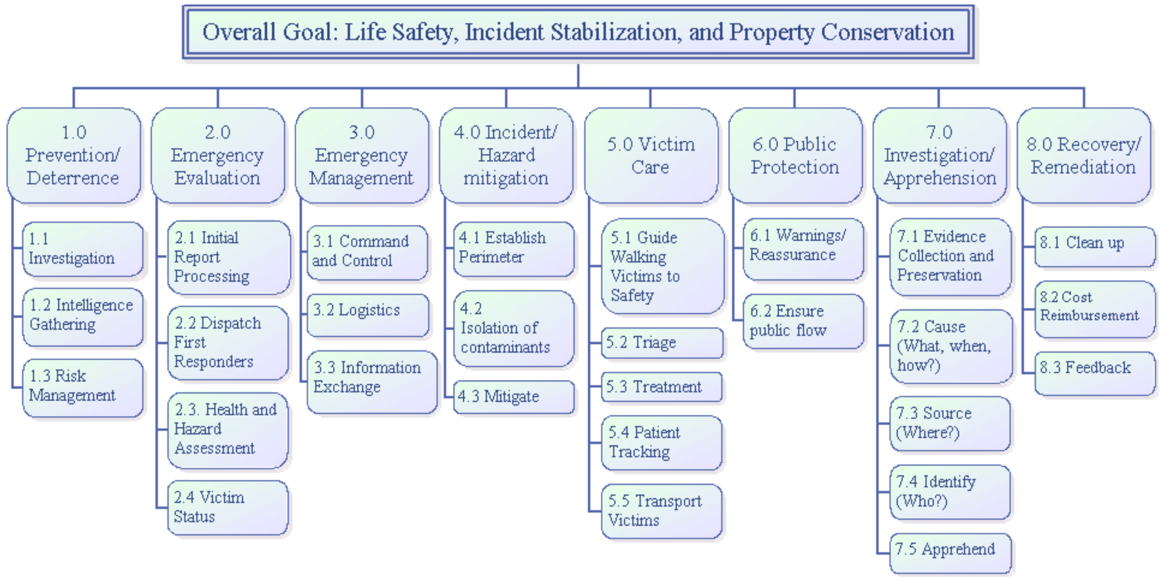


Figure 10: The resulting subject matter expert approved GDTA goal hierarchy.

Goal Hierarchy Goal Ordering

The horizontal ordering of the goals does not traditionally represent chronological order in the GDTA; however, a horizontal time ordering from left to right was loosely applied in this dissertation in order to better convey the relationship between the goals. The subject matter experts provided feedback regarding the timing of the goals and suggested that the goals be chronologically ordered. Figure 11 presents this ordering and the duration of the top-level goals in basic terms (i.e., no event, pre-event, event start, first minutes, first hours, days, and months.) Figure 11 was presented along with the preliminary goal hierarchy to facilitate communication with the subject matter experts during interviews.

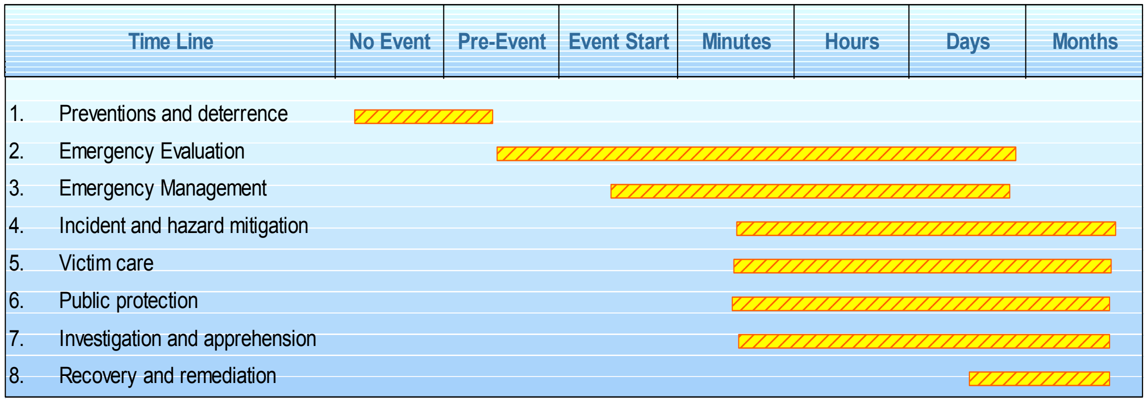


Figure 11: GDTA Goal Hierarchy top-level goal timeline.

Expanded goal-decision-SA structure

After the first complete review of the goal hierarchy with the subject matter experts, the expanded goal-decision-SA structures for the lowest level goals were developed. The expanded goal-decision-SA structures' purpose is to understand the SA requirements of the lowest level goals. Creation of the expanded goal-decision-SA structures was achieved by extensive subject matter expert review and through witnessing the system in action. The initial review focused on capturing decision questions and their related SA requirements. The subject matter expert feedback method was structured forms containing specific questions to determine the relevance of and the relationship between the goal, its general decision question, and its associated SA requirements.

Once each relevant decision question was accurately established, the focus became that of identifying the SA information requirements. The information requirements upon completion of the first review were incomplete and unspecific; therefore, sub-sub-goals were added in order to increase the granularity of the SA information requirements. Figure 12 provides four sub-sub goals for the sub-goal 2.0 Emergency Evaluation where each sub-sub goal also has an associated decision question.

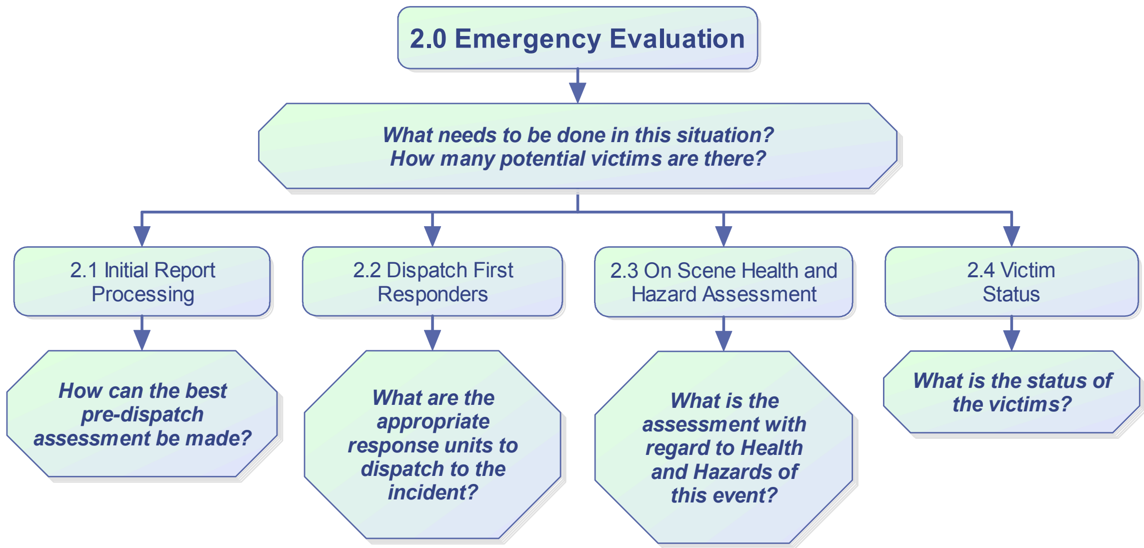
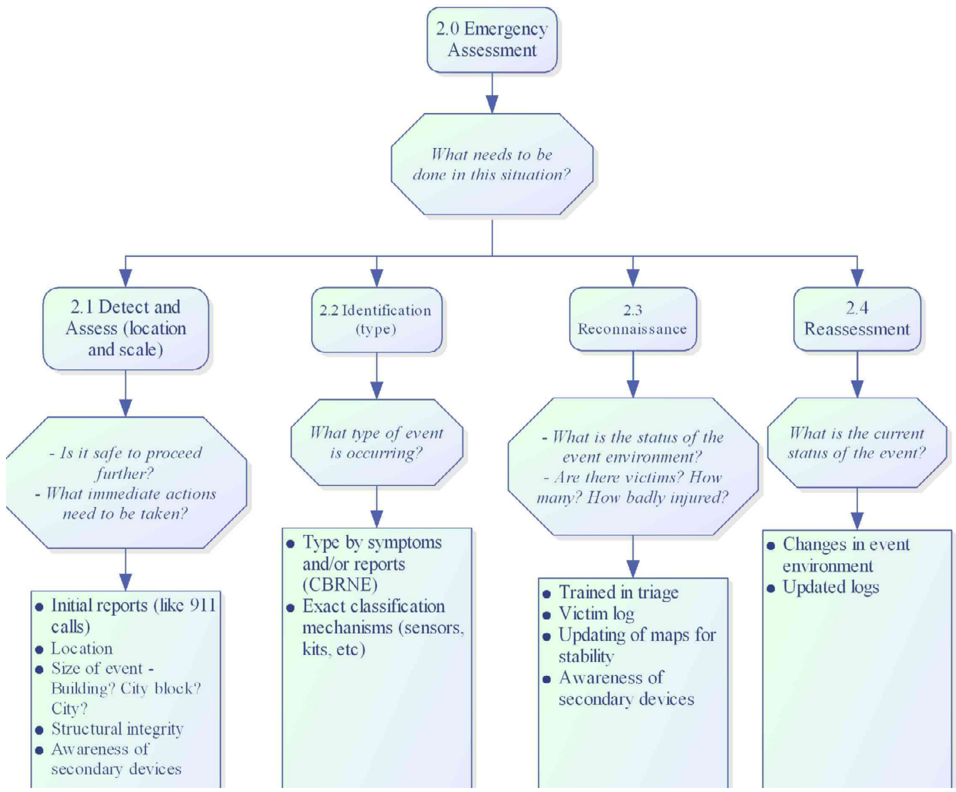


Figure 12: GDTA Sub-sub goals from sub goal 2.0 Emergency Evaluation.

The first SA information requirements revision asked the subject matter experts to provide feedback on a single list of proposed information requirements, see Figure 13. The vague questioning resulted in a review that was shallow and incomplete. Four categories were introduced to capture more of the information being provided by the subject matter experts and to facilitate more thorough discussions. These four categories are tools and resources, thought processes, people and groups, and information requirements. The purpose was to facilitate a clearer and more complete SA requirements review for each sub-sub-goal. The tools and resources are those objects that provide information used in SA perception and comprehension. Thought processes are mental notes or tasks that contribute to the comprehension and projection elements of SA. The people and groups, while not strictly an SA information requirement, assisted in identifying who was involved with a GDTA goal. The fourth category, information requirements, became the list of information items that are used to establish SA and accomplish the goal. A new form was created to effectively structure the subject matter expert responses in reviewing the proposed expanded structure and corresponding situational requirements; this form is partially shown in Figure 14.



Goal 2.1

Does the question below the box capture the general decision to be made in relation to this goal? Yes ☐ No ☐ if not, why? AnwserHere Are there other questions that would be appropriate? If so, please provide them. AnwserHere Review the items in the bulleted list below the question. What changes or additional information is needed to achieve this goal that should be included? AnwserHere

Figure 13: Simple SA structure review form along with an early version of the GDTA.

The Situation Awareness Requirements for this Goal:

Tools and Resources

- Classification mechanisms (sensors, kits, etc)

Thought Processes

- Awareness of secondary devices

People or Groups

- Public Health
- EMS
- HazMat
- US Army Civil Support Team
- - Search Team (4 people)
- - Medical Team (2 people)
- - Operation Team (2-3 People)
- US Army Core of Engineers

Information Requirements

- Reports describing the incident (Initial and periodic)
- Aerial Reconnaissance
- Real-time seismic data
- Collect other characterizing information (meteorological, readings from air monitoring devices, radiation meters, epidemiological data, lab results, reports from hospitals, clinics, and local public health departments.
- Collect or observe items that seem out of place (investigate items origin and meaning)
- guidance from Incident Commander (IC)
- Availability of time
- Availability of communication systems
- meteorological monitoring system
- emergency management information system
- changing conditions at incident site
- knowledge of plans and procedures

What "Tools and Resources" are required to attain this goal? AnswerHere

What "Thought Processes" are required to answer the decision question and attain the goal? AnswerHere

Who is specifically (i.e. "People or Groups") involved in attaining this goal? AnswerHere

What specific pieces of information are necessary to answer the decision question and attain this goal? AnswerHere

Figure 14: Expanded goal-decision-SA structure review form.

The categorized form results encompassed a more thorough and complete SA information requirements snapshot, as is evident in Figure 15. The expanded goal-decision-SA structure in Figure 15 is not the standard GDTA structure, but reflects the need to capture the additional necessary information. The modified SA requirement blocks are distributed among the sub-sub-goals in order to improve the relationship between SA requirements and the associated lowest level goals. Without categorizing the SA requirements, the feedback regarding the involved people and groups was minimal.

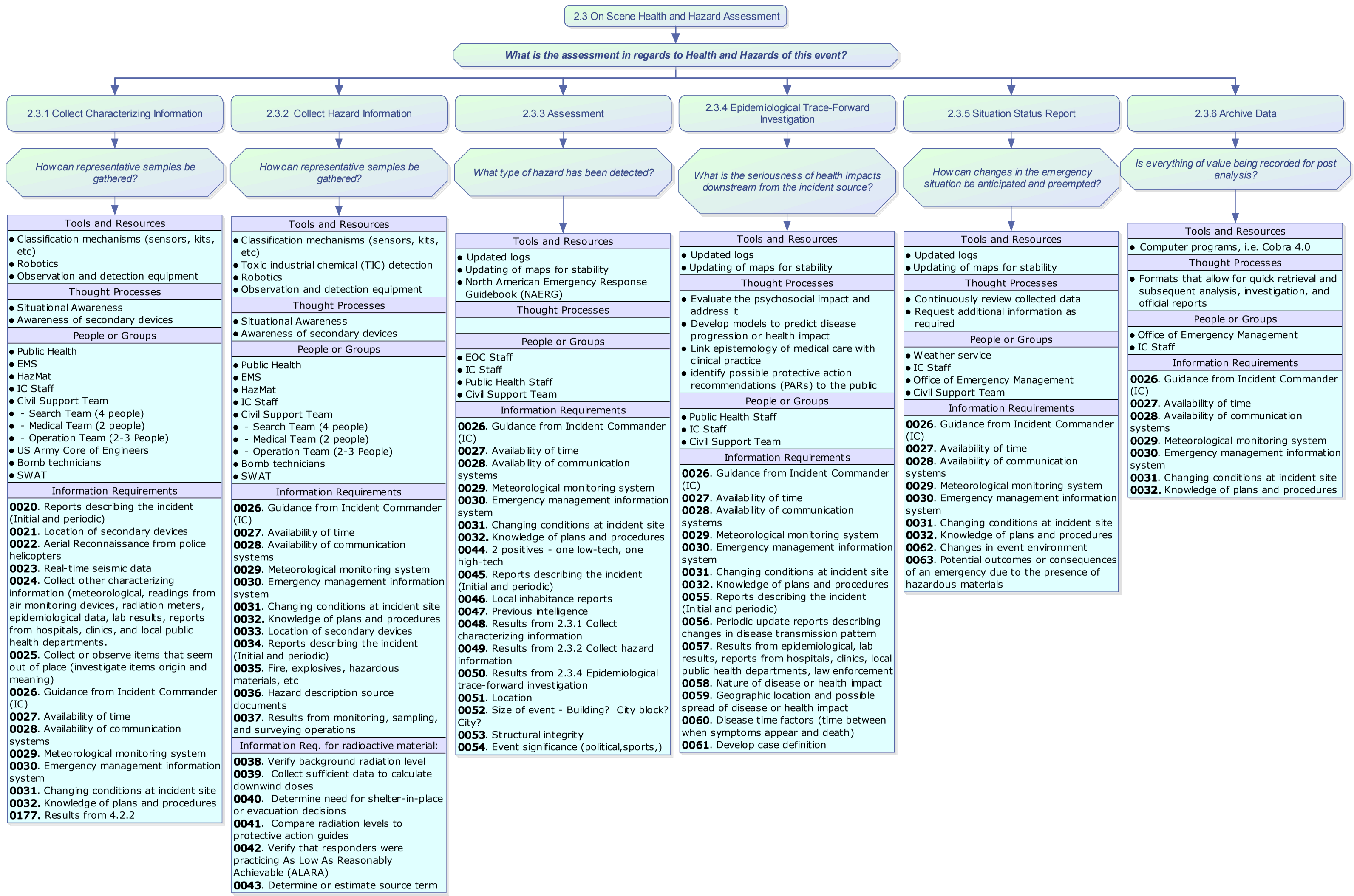


Figure 15: The modified GDTA Expanded goal-decision-SA structure for the sub-sub goals of sub-goal 2.3 On Scene Health and Hazard Assessment.

Numbering Information Requirements

The information requirements listed in the expanded goal-decision-SA structure have an additional feature not found in a standard GDTA. Each information requirement has been assigned a unique number (e.g., 0031). The unique number helped to establish where two or more information requirements, despite possibly slight wording differences, represent the same information requirements.

This feature was added to assist with combining the GDTA and CWA results into the Cognitive Information Flow Analysis (discussed in Chapter V). For example, the GDTA information requirement "Reports describing the incident (Initial and periodic)" is number 0045 and is part of GDTA goal 2.3.3 Assessment and is correlated with CWA's WDA object "Incident Reports" which is labeled as object "h" in Figure 19.

Cognitive Work Analysis

Methodology

The Modified CWA (Cummings, 2003) consists of seven stages: analysis of global social, organizational, and ethical factors; Work Domain Analysis (WDA); Constraint-based Task Analysis (CbTA); the creation of a simulated domain; analysis of effective strategies; analysis of social and organizational factors; and identifying demands on worker competencies (Figure 1). The Modified CWA begins by understanding the environment in which the system is used through the analysis of global social, organizational, and ethical factors and a WDA. As the environment is understood, the analysis transitions its focus from ecological elements to a cognitive analysis that accounts for the user's actions.

Since this dissertation's focus is on the development of a system of human-robot interfaces for use with novel robotic systems in the CBRNE response system, only the first four steps of modified CWA were employed. The last three steps will be addressed partly through user testing (see Chapter VII). This chapter presents the CBRNE response system results for the analysis of global social, organization, and ethical factors, WDA, and CbTA. The initial simulated domain results from the pilot study are discussed in Chapter VII.

Analysis of global social, organizational, and ethical factors

The analysis of global social, organizational, and ethical factors is designed to foster safer, more effective development of novel technology (Cummings, 2003). The analysis increases the designer's development of a "moral imagination" and an ethical mental model as this system has the ability to affect the welfare and safety of the public (Gorman et al., 1999). This analysis has three elements that are presented in the next three sub-sections: ethical factors, relevant social groups, and communication flow map.

Ethical Factors

The CBRNE response system equipment is currently predominately manual in nature, meaning that there is very limited use of information technology. The system's manual nature implies that the introduction of smart tools and robotic systems will be sensitive both ethically and socially. The greatest ethical factor put forth by Cummings (2003) is accountability, or who is responsible for mistakes that happen with the new system. Accountability cannot be overlooked, as any introduction of systems that support decision-making will be partly responsible for the success or failure of those decision outcomes. What makes the introduction of technology daunting is that these decisions usually directly affect the lives of individuals in the local environment as well as those in the interconnected global environment. Social tensions must be taken into account and eased. Therefore, the robotic systems must be presented as effective and reliable tools, not as human replacements, which they are not intended to be. Tools must be effective and reliable to establish user trust and increase adaptation and acceptance (Sheridan, 2002). Designing, developing, and testing new CBRNE technology will be insufficient to address the ethical and social issue without implementing a corresponding plan for incorporation, training, and failure detection. Without this plan and a focus on accountability, the technology will face difficult and incomplete acceptance in this very human-centric domain. This plan will be developed in parallel to the development and implementation of the proposed CBRNE robotic system and is left for future work.

Relevant Social Groups

Cummings (2003) expresses social factors through identifying the relevant social groups involved with the system being analyzed. One of the focuses of the relevant social groups is to identify both stakeholders and those who will in some way be affected by the new system. A combination of documents (District 5, 2005; FEMA, n.d.; Howe, 2004, 2005; Office for Domestic Preparedness, 2003; Shane, 2005), subject matter expert interviews, and exercise observations were used to construct the relevant social group map (Figure 16). The CBRNE response system is a human-centric system with many involved people and organizations; therefore, the relevant social group map displays 56 different individuals and organizations. The map groups the individuals and organizations roughly by type, with local individuals and groups being displayed on the top and right sides and the federal groups displayed along the bottom and left sides. The sheer number of individuals and groups potentially involved in a CBRNE response provides a glimpse into why the CBRNE incident response is so complex.

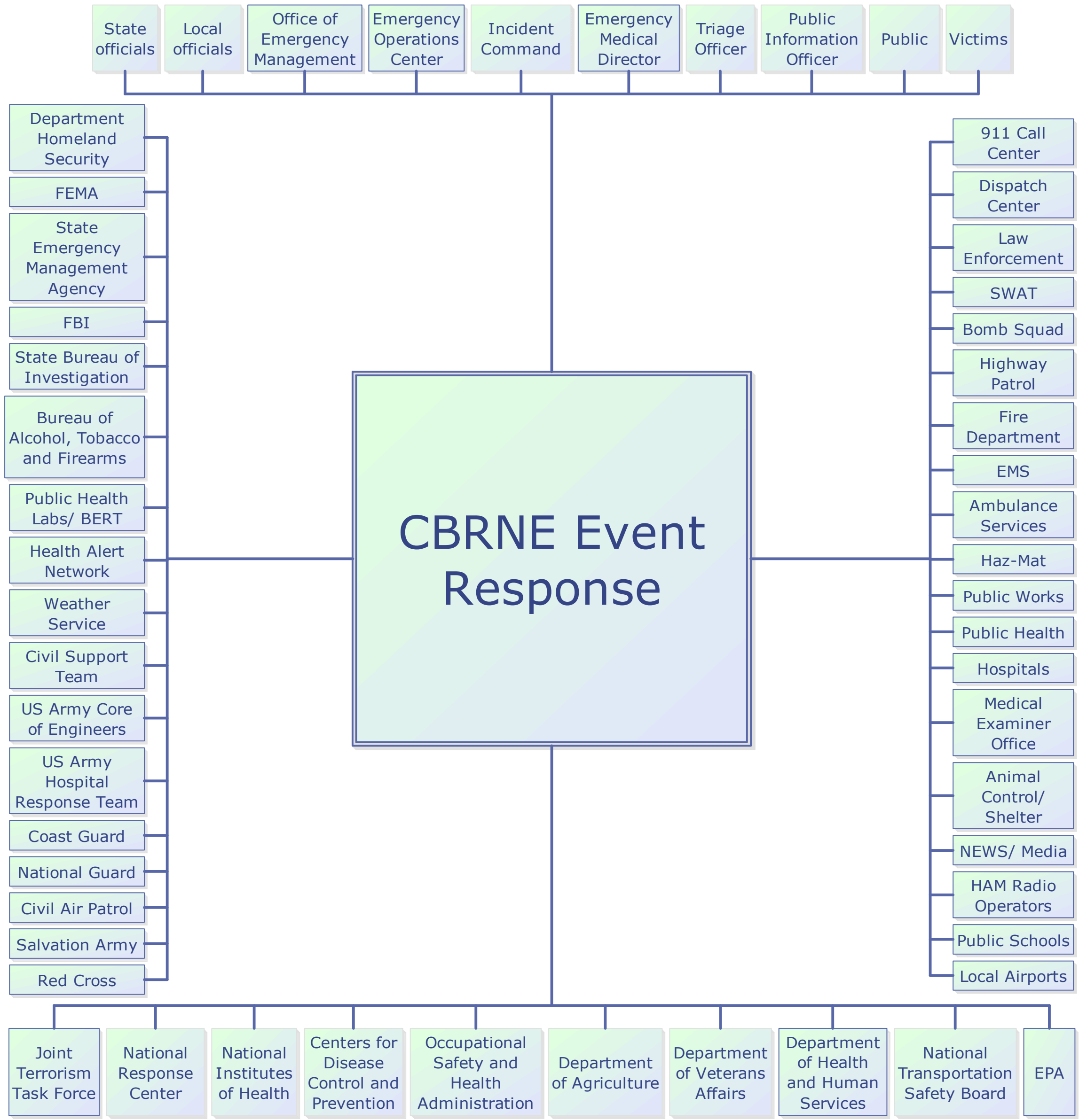


Figure 16: The CWA Relevant Social Groups of the CBRNE response system.

Communication Flow Map

Cummings (2003) introduces Communication Flow Maps into the mCWA as the step following the identification of relevant social groups. The goal of the Communication Flow Map is to illustrate how the different social groups communicate with each other and consequently how information is passed throughout the system. The CBRNE response system Communication Flow Map is presented in Figure 17 in a simplified and more readable version. The full version is presented in Appendix B. The CBRNE response system Communication Flow Map does not explicitly depict all the groups identified in the relevant social groups map. The groups that interact with the Joint Operation Center and the Joint Information Center or the Public Information Officer only are not depicted, as their impact on the robotic system will be minimal and their inclusion would simply add undue complication and clutter to the Communication Flow Map. The lines in the Communication Flow Map represent direct and authorized communication interactions; however, in practice, according to the subject matter experts, communication occurs outside of these specific connections due to personal relationships. For example, the Unified Command and a Law Enforcement agent may be good friends and they may communicate directly, although organizationally they do not communicate directly.

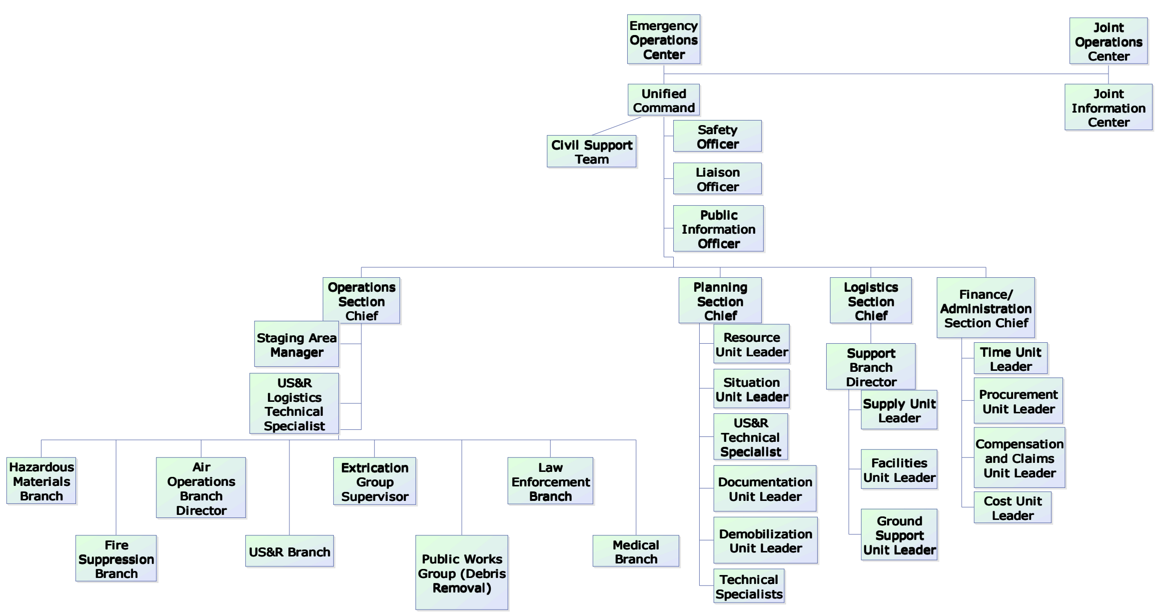


Figure 17: The simplified CWA Communication Flow Map of the CBRNE response system.

Work Domain Analysis

The WDA focuses on understanding the relationships between subsystems and components and is often graphically represented as an abstraction decomposition table (J. Rasmussen, 1985). The WDA in this dissertation began with a review of the literature, manuals, procedural documents, and reports regarding the system's operations in order to discover the subsystems of the CBRNE domain (Coast Guard, 2006; District 5, 2005; FEMA, n.d.; Shane, 2005; Office for Domestic Preparedness, 2003; US Army Corps of Engineers, n.d.; Howe, 2004, 2005). The Homeland Security *Planning Scenarios Executive Summaries* (Howe, 2004), subject matter expert interviews, observed exercises, and preliminary GDTA results provided the means to divide the overall CBRNE response system into different categories and sub-systems as defined in Figure 18. Figure 18 depicts three categories: Management Response System, Health Response System, and Hazard Reponses System. These three categories are abstract functions of the overall goal of "Life Safety, Incident Stabilization, and Property Conservation." The three categories are comprised of eight sub-systems (Figure 18).

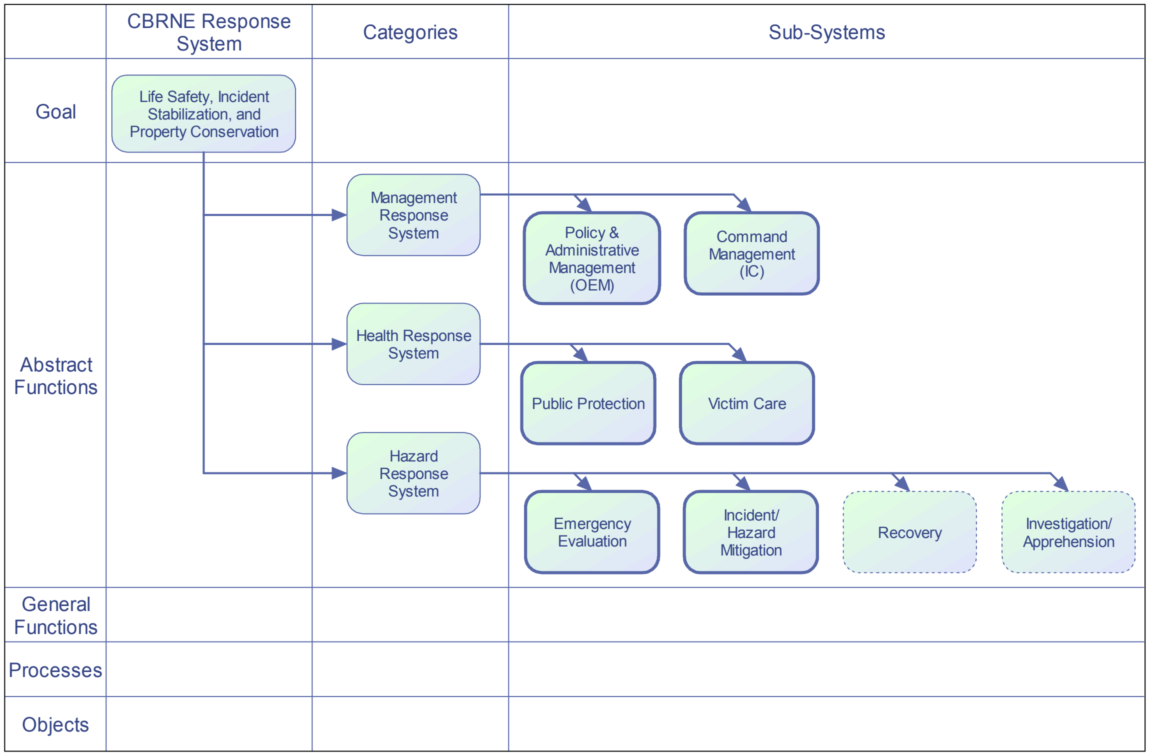


Figure 18: The Work Domain Analysis of the CBRNE response system, top levels only. The abstraction functions that have a bold border are the ones relevant to robotic systems.

After identifying the system's categories and subsystems, the next step in a WDA is to identify the priority measures, general functions, processes, and objects that belong to those subsystems. The Emergency Evaluation subsystem WDA is presented in Figure 19 and has been reviewed and validated by subject matter experts.

The Emergency Evaluation system WDA has two sub-systems: Life Safety Assessment and Victim Status and Awareness. The Victim Status and Awareness overlaps with the Victim Care system and, therefore, is continued in that WDA, presented in Appendix B. The Life Safety Assessment contains four general functions: Hazard Identification, Collect Data, Simulation, and Archive Data. These general functions are then broken into functional units, which are linked to processes. These general functions and processes are associated with a number of object components, which represent the tools and physical objects used during Emergency Evaluation. Throughout the WDA, letters (e.g., “a)”) have been added to the node names. These letters were added to provide a means of uniquely identifying individual nodes in conjunction with a row and column number. For example the node “Hazard Assessment” in Figure 19 is uniquely identified as 2.3.a meaning it is in the 2^{nd} row and 3^{rd} column with an “a)” before its name.

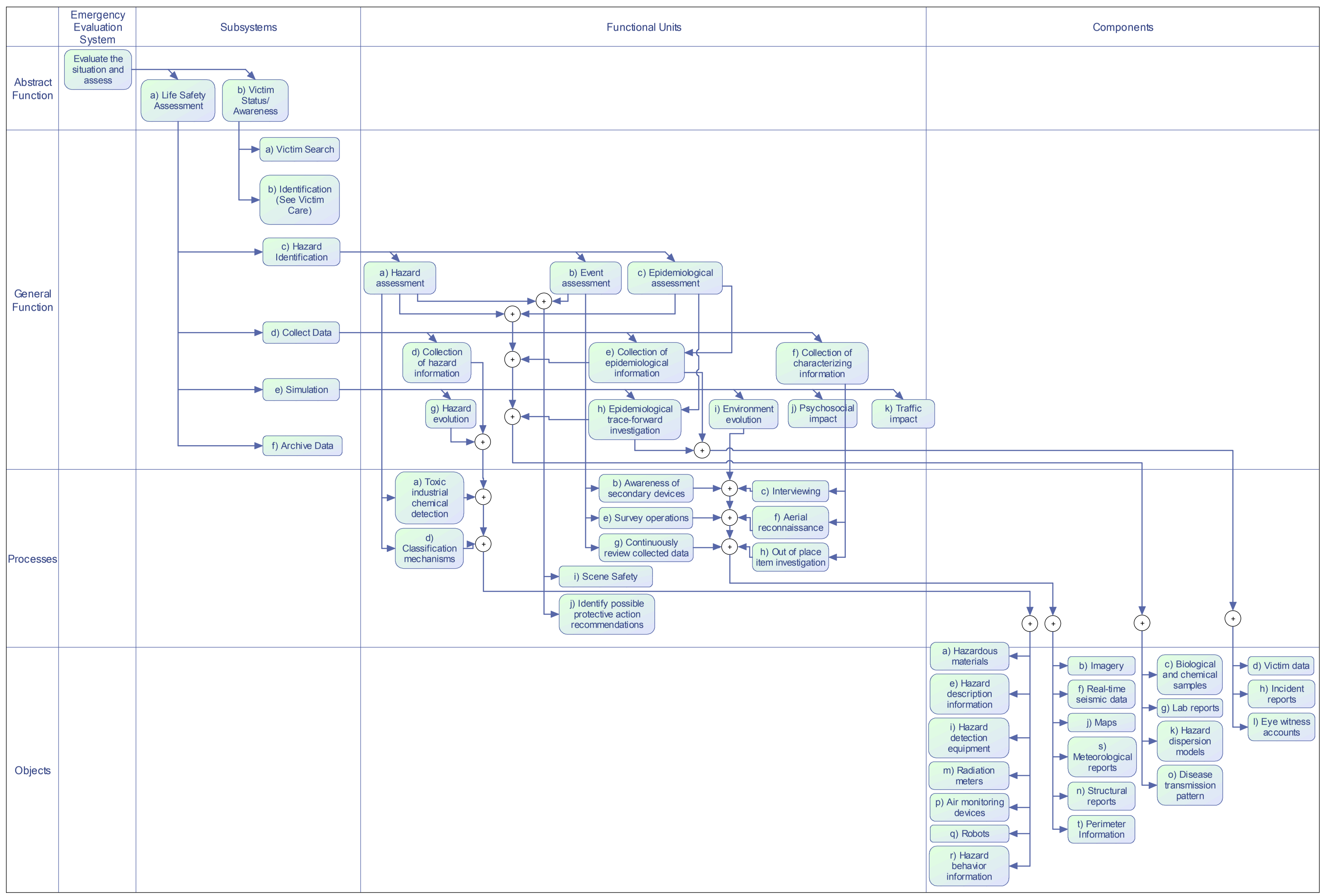


Figure 19: The WDA of the Emergency Evaluation subsystem.

Constraint-base Task Analysis

Whereas the WDA yields information regarding environmental constraints and provides an overall system perspective, the CbTA delves deeper and focuses on the action items, information, and relationships that are considered in the decision-making process (Vicente, 1999). The next two sections present the traditional method of representing a CbTA analysis and the method employed in this dissertation.

Decision Ladders

A CbTA is often visually represented as a Decision Ladder (J. Rasmussen, 1988), which is based on a two-step action-knowledge structure. The actions are linked together in an action-means-end relationship (Vicente, 1999). A Decision Ladder for Emergency Evaluation is provided in Figure 20, which represents knowledge states as oval shapes, action or information processing states as rectangle shapes, and the lines represent the paths between states. The paths in Figure 20 are all regular paths, or struts, as there are no leaps represented. The Decision Ladder is constructed based on careful analysis of the information provided in Figure 19 and from the literature review, subject matter expert interviews, and exercise observations. One of the most interesting discoveries in Figure 20 was the presence of three loops, all returning to the collecting environmental samples activity. The smallest loop provides information regarding how dangerous the environment is to the responders, that is, whether responders can enter the field. The second loop, which only occurs after the first loop, provides information concerning how safe the physical environment is for the responders, that is, whether responders can perform their responsibilities. The third loop is the primary loop, as the search action is performed. The return of the search loop implies that if the conditions of either of the other two loops changes, this loop will not repeat until the situation is reassessed as relatively safe. Figure 20 clearly shows the hierarchy of needs: the search occurs only if the structure is relatively stable and the assessment of the structure only occurs if the environment is relatively safe.

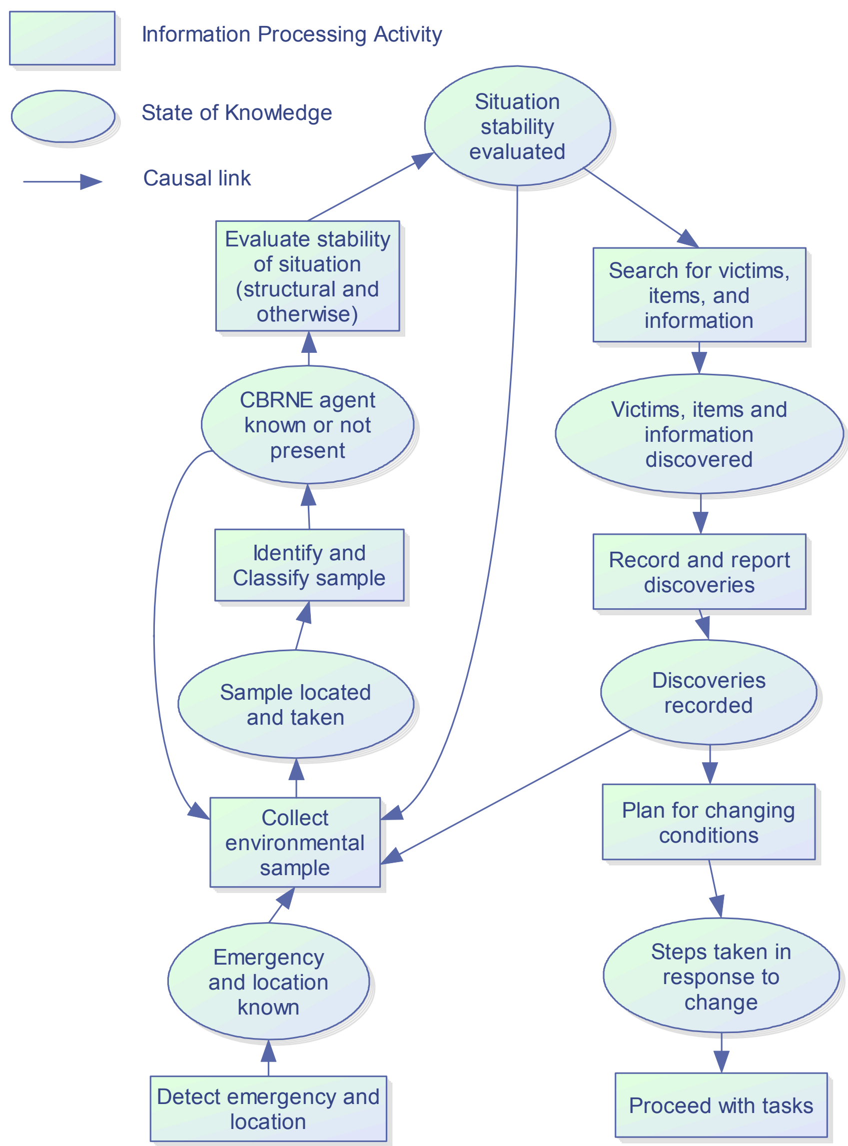


Figure 20: The CbTA Decision Ladder for Emergency Evaluation.

State-charts

The CbTA is traditionally represented with Decision Ladders (Vicente, 1999) which are based on Finite State Machines. However, when a Decision Ladder involves more than one decision sequence or the decisions overlap in time, the Finite State Machine model is inadequate, as it cannot represent concurrency and decisions succinctly. Multiple decision sequences, timing, and hierarchical relationships are a characteristic of team-based domains. Capturing these constraints is paramount to understanding the team decision-making process (Gonzalez, 2004). Therefore, Statecharts are proposed as an alternative to Decision Ladders because Statecharts can represent decision concurrency and hierarchical relationships succinctly. Statecharts (Harel, 1987) are a software engineering tool that has been applied to human-computer interaction (Loer & Harrison, 2003). Statecharts have similar expressive power as the Hierarchical Task Analysis (HTA) (Shepherd, 2000), discussed in Chapter II; however, HTA can represent an entire domain while the CbTA focuses on a particular task.

Figure 20 provides a Decision Ladder for the CBRNE response system sub-system Emergency Evaluation, while Figure 21 provides the corresponding Statechart approach. The Decision Ladder method does not clearly represent that all presented decisions occur only when it is safe to do so. This element is easily expressed in the Statechart via the embedded hierarchy (i.e., the elements inside another element can only occur if the parent element is the current state). Furthermore, the Decision Ladder has difficulty representing the concurrent activities, as it must enumerate all combinations of active tasks. For example, a simultaneous evaluation of the environment and structural integrity is required prior to responder entry and continues during the victim search. If dangerous conditions arise, the rescue personnel abandon the victim search and seek safety. These concurrent and hierarchical relationships inherent in the Emergency Evaluation task cannot be represented in a Decision Ladder without an excessively large number of states.

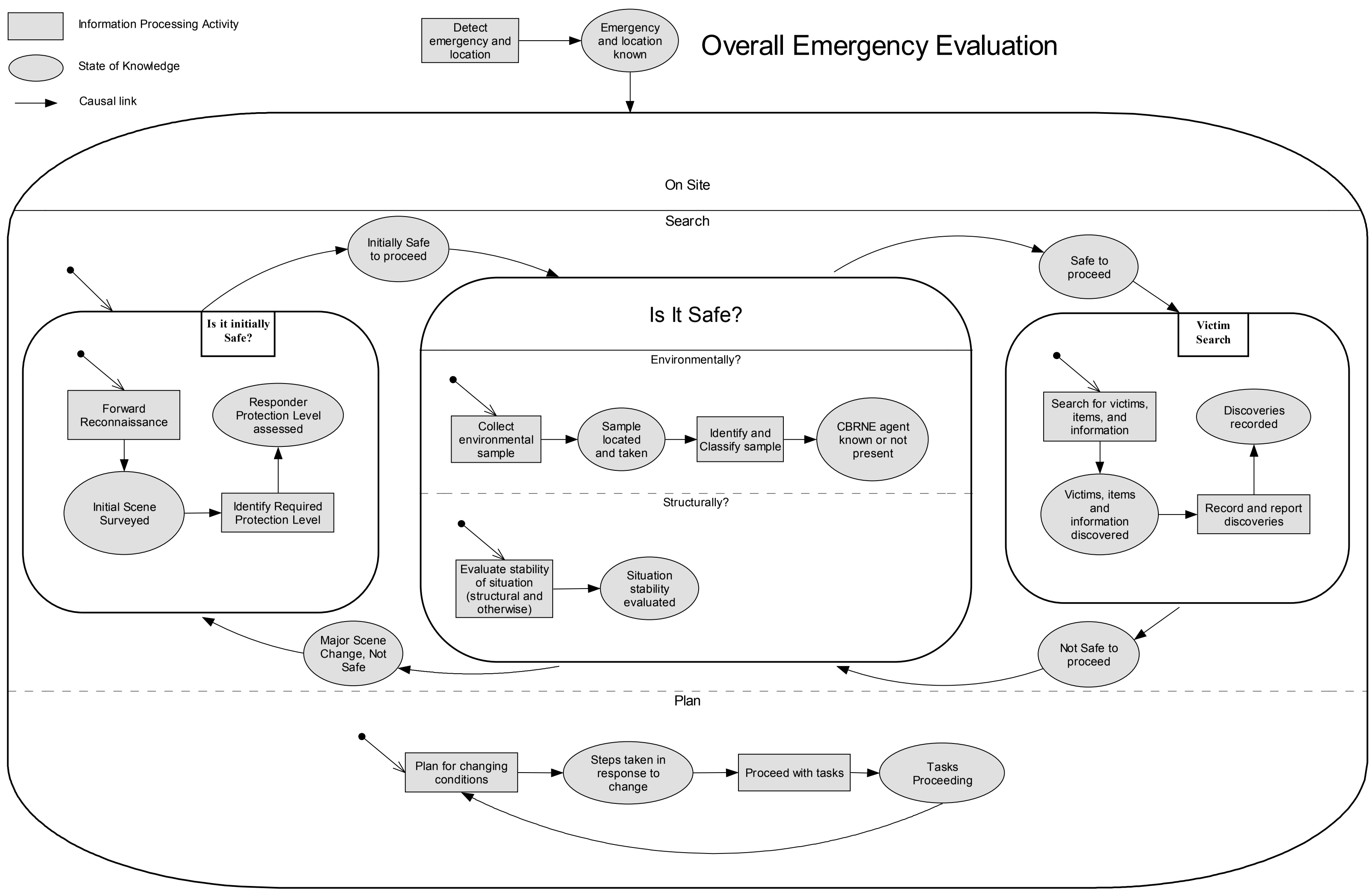


Figure 21: The CbTA State-chart version of Emergency Evaluation.

The use of Statecharts over Decision Ladders in the CWA has proven to be better in capturing complex team-based decision-making. The ability to capture the hierarchical and concurrent aspects of decisions is essential as they directly affect decision-making.

The Emergency Evaluation Example with Robots

At the beginning of this chapter, an emergency evaluation example was presented as it is currently conducted without robots. After conducting the GDTA and mCWA analyses, the entire scenario text was modified to include robots and how they may assist with and alter the CBRNE response system (see Appendix D). The following example is a small excerpt from the modified scenario text that corresponds with the original scenario text presented earlier in this chapter and represents how robots may alter the incident response.

> At 1:05pm, First Responders begin to arrive at the scene and immediately deploy robots for detection, identification, and scene tracking. The responders and the robots report that there has been an explosion at the TN Tower. Using the robots, the responders report that the west side of the TN Tower has been torn off and has collapsed into the building about 150 feet wide and 100 feet into the building and upwards of approximately 300 feet and that several small fires and a damaged portion of the TN Tower have been reported. The aerial robots indicate that people are walking around dazed, confused, and bleeding. Those that are victims start being assessed by medical initial assessment configured robots. Those victims that can be transported away are starting to be moved away via the medical victim transportation configured robots. There are bodies and body parts visible lying on the ground. The debris in the street is slowing down responders; however, they are using their resource-hauling robot to help them carry their equipment around the debris. A decontamination system, a robotic system is being deployed to thoroughly decontaminate the team from possible exposure to harmful agents.
>
> At 1:08pm, Additional First responders arrive on scene to find many Good Samaritans are on the collapsed structure trying to help. They instruct the

> Good Samaritans to limit damaging the debris and deploy aerial robots to recon into the area preventing more Good Samaritans from getting hurt.

The modified scenario text was described to subject matter experts and they found the robot possibilities intriguing and the assistance provided by the robots to be plausible and potentially very useful. The following is a description of how the robots altered and affected the response.

The first change introduced is the rapid deployment of the robots to detect, identify, and track the scene, providing a potentially richer initial report and scene assessment. The early assistance in assessing the scene for an initial report is especially useful if the responders must suit up in their personal protective equipment, which is cumbersome, reduces their field of view and maneuverability, and requires up to half an hour to prepare. The second change is that the robots, not the responders, are in the area observing the TN Tower's damage and civilian and victim activity. Deploying the robots in the area allows the responders to remain at a safer distance, thereby reducing their health risk. The next change in this short example is that the decontamination is performed by a robotic system, ensuring a level of confidence in the decontamination as well as removing the need for the responders to setup the system, a task that they must perform before being able to enter the hazard zone. Setting up the decontamination equipment took over thirty minutes during one sub-scenario observed during a full-scale exercise and those early minutes are critical in saving lives, as was repeatedly expressed by the subject matter experts. The last change is deploying aerial robots to perform reconnaissance of the area. Aerial robots may execute a survey task more quickly than human responders, which may reduce the health risk to Good Samaritans and responders.

Discussion

The combination of GDTA's directness and its information requirement focus combined with the broad and detailed mCWA has provided a much more specific and insightful domain analysis then either method can in isolation. Table 1 captures the most important strengths (top row) and weakness (second row) of the GDTA and the mCWA discovered during their application to the CBRNE response system.

Table 1: The important strengths and weaknesses of standard GDTA and mCWA along with the advantages of the modifications outlined in this paper.

	GDTA	mCWA
Standard Strengths	• Focuses on goals with defining decision questions. • Focuses on Information Requirements needed for decision making • Employs a hierarchical goal tree.	• Identifies stakeholders or relevant related social groups. • Captures the communication flow or organizational structure. • Represents the partial ordering of decision processes. • Models the constraints of the work environment.
Standard Weaknesses	• Task timing constraints and concurrency not adequately represented.	• Dense, higher learning curve due to complex relationships making it more difficult to explain to and discuss with SMEs. • Unwieldy abstraction-decomposition space for broad scope domains. • Task timing constraints and concurrency not adequately represented.
Modifications	• Provides partial chronological goal ordering. • Employs more comprehensive information requirements. • Identifies unique information requirements.	• Represents concurrency (or parallelism) and hierarchy of decision processes more clearly. • Sub-divisions provide more understandable abstraction-decomposition spaces.

The GDTA provided a workable understanding of the CBRNE response system and represented this knowledge in a visual structure more familiar to the subject matter experts than the mCWA. However, mCWA captured elements outside the GDTA's scope such as the global social, organizational, and ethical factors. The GDTA was easier to discuss with and present to subject matter experts than the WDA was primarily because the WDA requires a higher learning curve due to representing more complex relationships along its two axes. The GDTA representation is similar to a standard organizational hierarchy chart, with which the subject matter experts were familiar. The GDTA's strength of focusing on goals, tasks, and information requirements also map more cleanly to the existing CBRNE documentation, because the documentation was goal orientated in nature. The subject matter experts found that the GDTA supported their decision-making terminology clearly and succinctly partially due to its focus on information requirements. To further facilitate better communication with subject matter experts and to better understand the response activities represented in the GDTA, the GDTA was modified to provide partial chronological goal ordering (Table 1, bottom left cell). The broad CBRNE scope required two additional modifications regarding the information captured in relation to goals and decisions.

The original information requirement component of the GDTA was expanded to include categories of information: tools and resources, thought processes, people and groups, and information requirements, which provided a richer understanding of the elements that influence a decision. The mCWA does represent people and groups through the mCWA's communication flow map and relevant social groups; however, it does so in a different but complementary manner. The mCWA was able to capture more groups than the GDTA and was able to represent their communication paths. However, the GDTA was able to represent the associations between people and groups and individual goals. This GDTA modification is particularly useful in identifying the relationships between various people and groups and their involvement with various parts of the CBRNE response system, which the completed mCWA does not capture. Identifying these relationships provided the ability to know which individuals and groups will be affected when UVs assist with particular goals. Therefore, the manners in which the modified GDTA and mCWA represent people and groups are different and complementary.

Another GDTA modification was to assign a unique number to each information requirement, which allowed for unique identification independent of wording across tasks and groups. One advantage of the numbering is identifying all the goals that will be affected when the UV provides a particular information requirement. However, even with the numbering it was not easy to identify the flow of information. A new technique develop to address this limitation was developed and discussed in Chapter V.

The GDTA and standard mCWA both do not adequately represent task timing constraints and concurrency, which is vital to team-based decision-making (Table 1, second row). This issue led to the modification of the mCWA's CbTA to use Statecharts. The use of Statecharts provided the needed representation of task timing constraints and concurrency.

Due to the broad scope and nature of the CBRNE domain, employing both GDTA and CWA balanced each methods' strengths and weaknesses; furthermore, the additional modifications increased the representational abilities of both methods and compensated for common weaknesses. Greater than the sum of their parts, both techniques have been useful in viewing the many facets of the CBRNE domain. The synergy provided by using both GDTA and mCWA concurs with the results of Miller & Vicente (2001), Jamieson et al. (2007), and Kaber et al. (2006) that using a goal-based analysis (e.g., HTA or GDTA) compliments CWA, especially CWA's WDA. However, the findings in this dissertation regarding the individual strengths and weaknesses are possibly different from those reported by Miller & Vicente (2001). Miller & Vicente (2001) felt that the HTA was not as useful as the abstraction decomposition (i.e., WDA) for identifying information requirements. We, however, found the GDTA more beneficial than WDA for identifying information requirements. This finding may be an artifact of the order in which the analyses were conducted or because of the differences between the GDTA and the HTA. Miller & Vicente (2001) conducted the WDA prior to the task analysis (i.e, HTA); whereas, we conducted the task analysis (i.e., GDTA) mostly before the WDA. We believe the most likely reason, however, is found by examining the differences between GDTA and HTA. The GDTA was explicitly designed to expose information requirements (Endsley et al., 2003) by extending the basic HTA structure by associated low-level goals with information requirements and decision questions.

The application of mCWA and GDTA has demonstrated undeniable relationships between these techniques. Figure 22 illustrates the relationships between specific elements within the techniques using standard logic and functional notation. The comparison direction flows from the mCWA to the GDTA in order to clarify the explanation; the reverse flow also holds. The connections do not imply that every GDTA element is represented in the CWA, but that a possible correspondence exists.

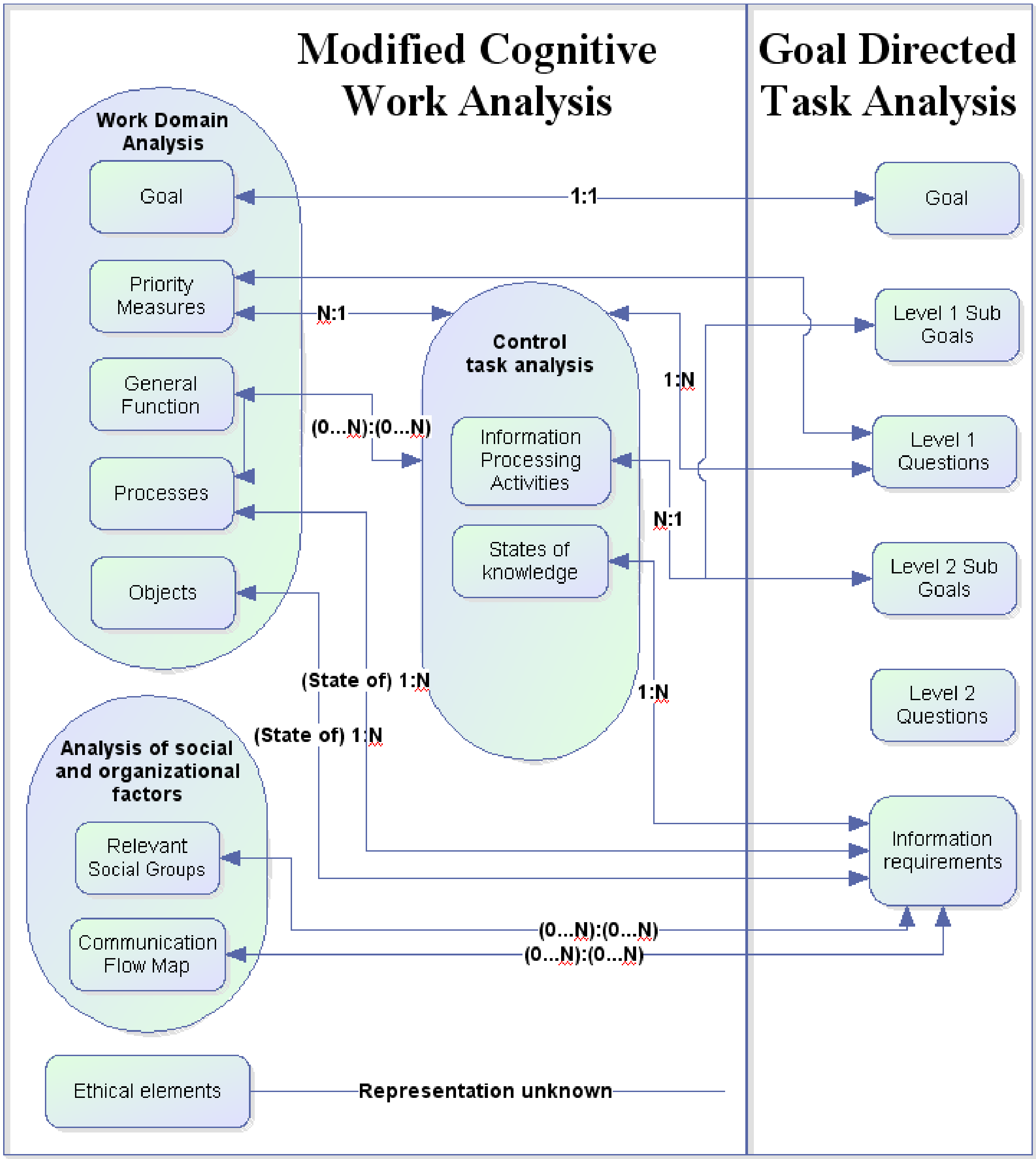


Figure 22: The functional relationship between GDTA and mCWA.

The WDA goals and priority measures directly correspond to GDTA goals and level 1 questions with little conversion (Figure 22). The WDA process states and objects also directly correspond to GDTA information requirements. However, only indirect relationships exist between the WDA's general function component and the GDTA via the CbTA relationship to the GDTA's sub-goals and information requirements. Similarly, the relevant social groups, the communication flow map, organizational factors, and some of the CbTA knowledge states are represented in the GDTA information requirements. The merging of different mCWA elements into the GDTA information requirements is part of the reason why the goal-decision-SA structure was extended by categorizing the information requirements (Figure 15).

When the GDTA and mCWA are conducted in a closely-coupled manner, as was the case with the CBRNE analysis, the result is the ability to more readily integrate the results of the two techniques (Jamieson et al., 2007). The results show how the current CBRNE response system is extensively human-centric and how little the humans rely on any form of intelligent systems or equipment. This finding further confirms that incorporating new robotic systems is fundamentally a paradigm shift for the CBRNE response system. The overall analysis identified appropriate multiple UV tasks (Humphrey & Adams, in press), User Levels (Chapter IV), and the associated information requirements and capabilities required to support and supplement the existing human-based CBRNE incident response. We believe that our analyses led to the discovery of UV appropriate tasks and requirements that would not have been identified by a traditional engineering design process.

Limitations

The modifications to the GDTA and the mCWA allowed the techniques to be expended to analysis the CBRNE domain; however, a few limitations still remain. Neither the GDTA nor the mCWA explicitly focus on the flow of information throughout the system. The flow of information includes information production and information transformation. For example, GDTA does list information but it does not discuss how any particular goal produces information or how goals could transform information. The mCWA's CbTA is an information-driven CTA technique; however, its two step structure limits how it can represent information flow. The CbTA is focused on the path of thought (i.e., decision to knowledge state) and not the path of information (e.g., hazard readings). The second limitation still present after the modifications is not as obvious, but is nevertheless a important limitation: one must perform *two* CTA techniques in order to provide all the required analysis attributes for domains like CBRNE. The results have demonstrated how the GDTA and the mCWA balance each others' weaknesses and thus one must perform both techniques and then correlate the results. Performing two CTA techniques increases the analysis time and adds to the results complexity. For example, each technique was compared with each other to ensure related items used the same language and structure wherever appropriate.

Conclusion

The CBRNE domain as analyzed in this chapter has a much broader scope both in terms of the number of components, decision-makers, and environmental issues than traditional, narrowly focused, physical-based domains analyzed with CTA techniques. The broad CBRNE domain benefited by applying the two different yet complementary cognitive task analysis methods: GDTA and mCWA. The synergy provided by applying these two methods in a closely-coupled manner yielded richer results than either method could have provided in isolation. Furthermore, the broad scope of the CBRNE domain required a number of modifications to the traditional GDTA and mCWA methods in order to facilitate information capture and translation to design requirements. This chapter's contribution is the delineation of the modifications to the GDTA and the mCWA components in order to support the CBRNE domain analysis.

CHAPTER IV

USER LEVELS

The CBRNE response system is a human-centric system that can involve thousands of responders and many thousands of civilians and victims. The CWA Relevant Social Groups diagram in Chapter III (see Figure 16) identified 56 different individuals and organizations that may be involved with the response. The introduction of a new robotic system will affect the workflow, decision-making, and responsibilities of the responders. Each CBRNE event response differs dramatically in scope; therefore, it is impractical to define user roles for each potential responder that may interact directly or indirectly with the robotic system. The individual responders and victims have been abstracted into ten User Levels based on the IUCMCI-Student Manual (FEMA, 2005), subject matter expert interviews, and GDTA and CWA results.

The Five Factors

The ten User Levels are defined by five factors: the human-robot interaction role (HRI Role), the hazard zone occupied (Zone), the information types provided by the robotic system (Information Type), the user's responsibilities to the robotic system mission (Responsibilities), and real responder CBRNE roles (Real Roles). These five factors are discussed in the following sections.

HRI Role

The User Level differentiates the type of interaction between the users and the robotic system. The User Level concept is based on the human-robot interaction (HRI) roles defined by Scholtz (2003) and extended by Goodrich and Schultz (2007). This dissertation includes five of the defined interaction roles and adds a new interaction role. The five pre-defined HRI roles are supervisor, operator, peer, information consumer, and bystander. The supervisor role has authority over and manages the other HRI roles and can monitor and review robots. The operator role works “inside” the robot(s), directing its behaviors and actions either by modifying parameters or through teleoperation. The peer role works alongside the robots, in the same common physical space, towards completing a shared assignment while interacting with the robots as if they were teammates. The bystander role is similar to the peer role in that the person resides in the same common physical space as the robots; however, the bystander does not work intentionally towards some shared assignment or goal. The information consumer does not directly interact with the robots, but rather uses information that originates, at least partially, from the robots.

Abstract Supervisor Role

The new HRI role defined in this dissertation is the abstract supervisor role. The abstract supervisor is an individual who resides above the supervisor in the chain of command and is responsible for a broad set of system components, which includes robots and their operators as well as responders not related to the robots. The abstract supervisor is also a problem holder; that is, an individual who sets the goals and objectives. The abstract supervisor's interaction with the robots is partially as an information consumer and partially as a supervisor. The abstract supervisor consumes information that originates from the robots; however, this information is often abstracted in such a way that the abstract supervisor may not recognize the information originated from the robots, similar in concept to the information consumer. However, the abstract supervisor, unlike the information consumer, can modify the system response objectives and goals in response to the information reviewed, thereby affecting the tasks the robots are or will be executing, similar to the supervisor role, albeit in a more abstract manner.

The following example illustrates the different interaction roles and the complementary interaction between the abstract supervisor, supervisor, and operator User Levels. An aerial robot can record a chemical reading as part of its surveillance task of a particular area. The operator completes the surveillance task by successfully navigating the aerial robot. After monitoring the task, the supervisor notes two things: the task was successful and the chemical reading needs to be reported to his superior, the abstract supervisor. Upon review of the report, the abstract supervisor realizes that the chemical reading corroborates evidence another agency is reporting and decides that this region should be evacuated. The abstract supervisor issues a new goal to evacuate the area, which then causes the supervisor to direct this operator to change the robot's task from surveillance to monitoring and assisting with the evacuation.

Zone

The CBRNE personnel function in three hazard zones (Zone): Hot Zone, Warm Zone, and Cold Zone. The Hot Zone is where exposure to the hazard is the most severe, requiring the highest level of personal protective equipment (US EPA, n.d.), as warranted by the particular hazard. The Hot Zone area is determined by the hazard's area of greatest influence (e.g., a bomb's explosive radius). The Warm Zone is defined as the area surrounding the Hot Zone and is where that hazard's danger is present, but at limited levels and is unlikely to result in long-term or lingering damage to one's health. The Warm Zone starts at the edge of the Hot Zone and continues until the effects of the hazard can no longer be experienced. The Cold Zone is the area surrounding the Warm Zone and is the area in which the effects of the hazard are insignificant, but possibly detectable. The Cold Zone is everywhere outside the Warm Zone. Users are defined by the most dangerous zone to which they are likely to be deployed; however, it is very likely that users will be in less dangerous zones and can be temporarily deployed to a more dangerous zone.

Information Type

The information produced by the robots was abstracted into three basic types and presented to the CBRNE users: Robot External Status, Robot Internal Status, and Sensors. The Robot External Status provides information regarding a robot's situation in the world (e.g., information regarding whether the robot is still flying or whether it has crashed.) The Robot Internal Status provides information regarding the internal, or non-visible, functionality of an unmanned vehicle (UV) system, also known as a robotic system (e.g., battery voltage remaining, communications signal strength, or current motor amperage.) The Sensors provide environmental information acquired from a robot's sensor suite (e.g., chemical sensors, laser range finder, or video.) Each information type was assigned a number representing how abstract the information is as it relates to each User Level. The abstraction number is represented by an ordinal scale from 0, indicating no abstraction, to 4, representing the forth level of abstraction. This abstraction number does not imply that a User Level cannot obtain the information at a different abstraction level, but that this abstraction level is the User Level's primary representation.

Responsibilities

Each User Level has specific responsibilities during the CBRNE incident. These responsibilities were identified by the CTA methods (see Chapter III) and extrapolated to an incident response using robots, or unmanned vehicles. These lists of responsibilities are not inclusive, but rather represent the primary goals that each User Level is responsible for accomplishing. Listing the responsibilities provides a richer description of each User Level and its perspective scope in the CBRNE response system context.

Real Roles

Each User Level is associated with existing CBRNE domain human roles, as defined in the Unified Command Structure (Shane, 2005). The User Levels are abstracted from these real CBRNE domain roles according to how the real roles fit into the aforementioned four factors: HRI role, zone, information type, and responsibilities. The abstraction allows this model to be invariant to CBRNE domain role renaming or differences in incident organization structure due to resources, region, incident scale, and hazard scope. For example, when the incident is small and involves a single bomb, many of the CBRNE domain roles will not exist, as they will not be needed.

The CBRNE User Levels

The CBRNE response system abstracts the human responders into ten User Levels. These ten User Levels are defined by five factors: HRI Role, Zone, Information Type, Responsibilities, and Real Roles. Figure 23 provides the ten CBRNE response system User Levels and their corresponding five factors. The robot, or unmanned vehicle, is included at the bottom of the figure to illustrate how the information flows and changes as it progresses through the User Levels. The ten User Levels from bottom to top are Victims/Civilians, Direct Human Teammate, UV Specialist, Indirect Human Teammates, Team Leader, Division Chief, Logistics Technical Specialist, Staging Area Manager, Operations Chief, and Incident/Unified Commander. The arrows connecting information types at different User Levels indicate that the information is transformed, altered, or passed from one User Level to another. For example, the Logistics Technical Specialist User Level's Robot General Status information type is abstracted from the UV specialist User Level's Robot External Status and Robot Internal Status information types, thus the Robot General Status combines two information types and presents the information at a more abstracted, or less detailed, level, resulting in a higher abstraction number. The following sections describe each User Level.

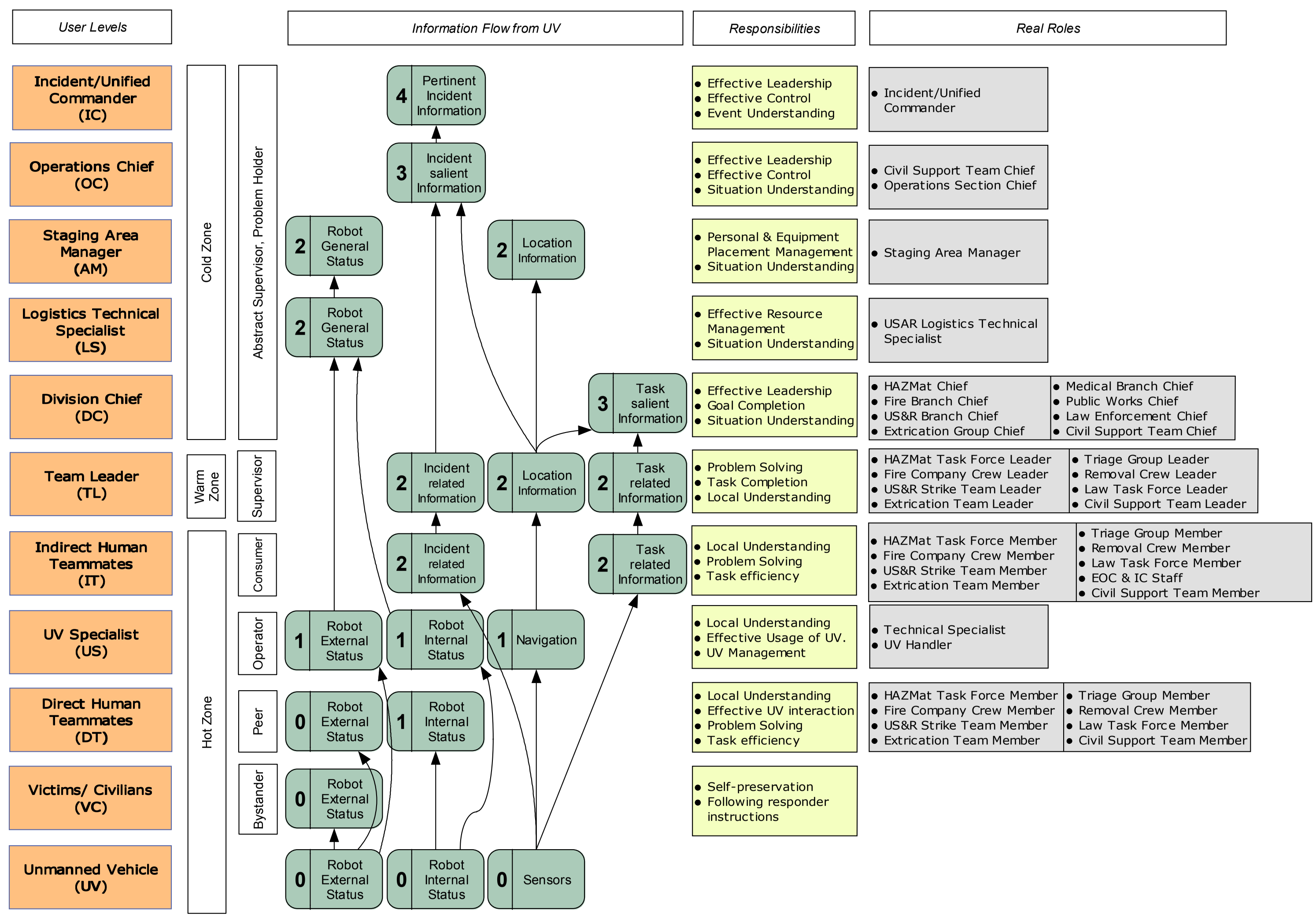


Figure 23: The CBRNE User Levels.

Victims/Civilians

The Victim and Civilian User Level represents bystanders (Scholtz, 2003). Victims require rescuing and both victims and civilians are present in the operational theater. Figure 23 indicates that these individuals may be in the Hot Zone. These individuals may observe the UV's External Status in a raw, non-abstracted form (i.e., abstraction level 0). It is unclear what, if any, effect the information will have on these individuals as they are consumed with self-preservation actions and thoughts. Victims and Civilians have two primary responsibilities: self-preservation and following responder instructions.

Direct Human Teammate

The Direct Human Teammate interacts directly with UVs in a peer-based relationship (Scholtz, 2003) in the incident Hot Zone. This User Level is co-located with the UVs and can access an UV's External Status and possibly an UV's Internal Status via direct interaction with the UV (e.g., audio, lights, digital panels) or via a communication portal (e.g., PDA, smart phone, etc). Direct Human Teammate responsibilities include effective UV interaction or interaction in a manner to reduce communication errors; problem solving; and maintaining a local situational understanding in order to efficiently and effectively complete assigned tasks. A large pool of CBRNE responder roles may be classified as Direct Human Teammates, as shown in Figure 23.

UV Specialist

The UV Specialist is responsible for initiating and directing the UVs' decisions. The interaction between this User Level and the UVs will vary depending upon the UVs' capabilities. This User Level will typically remain in the Warm or Cold Zones and fulfills Scholtz's (2003) operator role. The UV Specialist receives direct UV information via the Robot External Status and Robot Internal Status and receives indirect UV information via the Navigation Information, which represents a composite of many sensor readings. The UV Specialist is responsible for effectively tasking the UVs and managing their high-level activities via goal/task assignments and direct teleoperation when required. The UV Specialist is expected to have a local situational understanding based on the UV provided information and is responsible for preventing the UV from negatively influencing the CBRNE response system. The UV specialist User Level represents a new role in the CBRNE response hierarchy, which may be termed a Technical Specialist or UV Operator (Goodrich et al., 2007).

Indirect Human Teammates

The Indirect Human Teammate User Level is comprised of two groups. One group directly interacts with the incident environment (i.e., in the Hot Zone) but interacts indirectly with the UV system, while the other group does support work in the Cold Zone. Both groups interact with the UV system as information consumers (Goodrich & Schultz, 2007), using UV provided information related either to the incident in general or to specific tasks. The responsibilities of the Indirect Human Teammate User Level are to have local situational understanding, conduct problem solving, and complete the assigned task as efficiently and effectively as possible. The real CBRNE roles encompassed in this User Level are vast, with the predominate roles being Hazardous Material (HAZMAT) Task Force Members, Fire Company Crew Members, Urban Search and Rescue (US&R) Strike Team Members, Extrication Team Members, Triage Group Members, Removal Crew Members, Law Task Force Members, Emergency Operation Center (EOC) and Incident Center (IC) Staff, and Civil Support Team Members.

Team Leader

The Team Leader User Level represents an onsite coordinator who supervises one or more responder and UV teams and takes the HRI interaction role of supervisor (Scholtz, 2003). This individual may enter the Warm Zone, but through new technology would ideally reside in the Cold Zone. The Team Leader requires abstracted information from the UVs, represented as the level 2 abstraction level in Figure 23. The Location Information is derived from the Navigation Information while both Incident Related Information and Task Related Information are derived from Sensors. Incident Related Information does not directly address the task but is relevant to other aspects of the response, for example, the possible identification of a secondary device in an open field when the current task is that of inspecting a building for structural damage. Team Leaders manage the UV Specialists and formulate tasks for the UVs and the overall mission. The Team Leader User Level responsibilities include maintaining a local situational understanding, problem solving, and completing the assigned task efficiently and effectively. There are many real CBRNE roles represented by this User Level, such as: HAZMAT Task Force Leader, Fire Company Crew Leader, US&R Strike Team Leader, Extrication Team Leader, Triage Group Leader, Removal Crew Leader, Law Task Force Leader, and Civil Support Team Leader.

Abstract Supervisors

Each of the remaining five User Levels are fulfilled by individuals who remain in the Cold Zone and are considered abstract supervisors. As the User Levels approach the apex of the CBRNE command hierarchy, the number of individuals who fulfill these roles decreases.

Division Chief

The Division Chief User Level oversees the activities of several Team Leaders and requires Task Salient Information that can be derived from the Location information and Task Related Information. Task Salient Information highlights and presents the most relevant aspects of the Task Related Information correlated with location. Such information for a structural assessment task may include the number of broken structural beams, number of stable walls, and status of gas and electrical lines. The Task Salient Information may include the status and location of the gas and electrical lines, which may inform other goals such as identifying a means to shut off leaking gas. The Division Chief reviews UV derived information and affects an appropriate response to the derived information. The Division Chief's CBRNE responsibilities include effective leadership over the Team Leaders, overall completion of tasks assigned to Team Leaders, and situational understanding. The real CBRNE roles represented by this User Level are HAZMAT Chief, Fire Branch Chief, US&R Branch Chief, Extrication Group Chief, Medical Branch Chief, Public Works Chief, Law Enforcement Chief, and Civil Support Team Chief.

Logistics Technical Specialist

The Logistics Technical Specialist User Level manages the resource allocation in a particular operational area. This individual is interested in the UVs' General Status, which essentially summarizes a robot's ability to perform a task successfully from a mechanical perspective. This information facilitates the ability to allocate resources appropriately based on need and potential equipment failures. If a UV is about to fail, the Logistics Technical Specialist can procure a backup. Essentially, this individual provides the necessary resources to effectively execute CBRNE tasks, including UV missions. The associated responsibilities of this User Level include effective resource management of technical equipment and situational understanding. The Logistics Technical Specialist User Level is representative of real CBRNE roles such as the US&R Logistics Technical Specialist.

Staging Area Manager

The Staging Area Manager User Level oversees the areas where new responders, or augmenters, gather before receiving role and task assignments. The Staging Area Manager requires the Robot General Status and Location Information, which are abstracted to higher level presentations providing key features specific to personnel and equipment placement management. The combination of Robot General Status and Location Information provides the ability to determine where new UV equipment should be deployed for effective utilization, along with the personnel required to accompany or operate the UVs. The responsibilities of this User Level are personnel and equipment placement management and situational understanding. The real CBRNE role represented in this User Level carries the same name: the Staging Area Manager.

Operations Chief

The Operations Chief User Level manages several Division Chiefs in order to fulfill the duties of a particular operational area. This User Level requires Incident Salient Information which highlights the most important elements within the Incident Related Information correlated with Location Information. For example, Incident Related Information gathered during a structural assessment task may include the identification of a secondary explosive in a nearby field, unidentified chemical residue on an internal building wall, or discovery of an out of place, yet relevant, old newspaper. Incident salient information may include the unidentified chemical residue, which can be used to spawn a new mission to recover and identify the chemical compound, perhaps resulting in the modification of the overall response. The Operations Chief User Level responsibilities include effective leadership, effective operations control, and situational understanding. The real CBRNE roles corresponding to this User Level are the Civil Support Team Chief and Operations Section Chief.

Incident/Unified Commander

The Incident/Unified Commander User Level resides at the top of the response leadership hierarchy and can oversee several Operation Chiefs. The Incident/Unified Commander guides the overall CBRNE response and represents the real CBRNE role of the same name; that is, the Incident/Unified Commander. This User Level is focused on Incident salient information, which is at a higher abstraction level then the information presented to the Operations Chief. For example, the Operations Chief may receive information regarding an unidentified chemical residue located in a building. If, once identified, the chemical is determined to be significant (e.g., a nerve agent) then the information is communicated to the Incident/Unified Commander. However, if the substance is identified as benign, such as baking flour, the information may not be communicated to the Incident/Unified Commander. The Incident/Unified Commander's responsibilities are to provide effective leadership, effective control, and incident understanding for the overall incident response.

Limitations

A limitation of the ten User Levels definitions are only applicable to the emergency response incident domain, which includes CBRNE incidences. These User Levels are design explicitly to represent a human-robot interaction style and are, therefore, not designed for use in other ways (e.g., interaction between responders or human to human interaction). The overall user level concept can be applied to any hierarchical organization that will utilize robots and has no other known limitations.

Summary

The overall importance of partitioning the CBRNE response system into ten User Levels is one part practical and one part design. The practical importance is that the CBRNE response can involve thousands of responders, civilians, and victims with at least 56 different affiliations; therefore, abstraction of the system users into ten levels makes understanding the users more tractable. The design importance is that the User Level, especially by identifying the information type needs, assists in developing a system of interfaces for interacting with the proposed robotic system. The defined User Levels are directly employed in the Cognitive Information Flow Analysis (discussed in Chapter V) to represent which responders interact with each function that processes and produces system related information. For the remainder of this dissertation, interface design will be focused on only two User Levels: UV Specialist and Operational Chief. Designing interfaces for the other eight User Levels is left for future work.

CHAPTER V

COGNITIVE INFORMATION FLOW ANALYSIS

Defining Cognitive Information Flow Analysis

Cognitive Information Flow Analysis (CIFA) is a new technique that was developed for this research as a method to integrate and bridge the GDTA and CWA results and the implementation of the proposed system. Unlike GDTA or CWA, the focus of the CIFA is the path of information through the system, both how the information is used and how it is transformed, thereby assisting in the development and integration of new systems.

This chapter starts with the motivation behind the creation of the CIFA, and then discusses the components of the CIFA and the inspiration for those components. The CIFA results, as applied to part of the CBRNE response system, are subsequently presented. The remainder of the CIFA results can be found in Appendix C. This chapter then compares the CIFA results with the GDTA and CWA results, followed by a discussion of the CIFA advantages and concludes with a summary.

Addressing CTA Issues

Three categories of Cognitive Task Analysis (CTA) techniques were reviewed in Chapter II concerning their ability to express the interconnectivity of the various subcomponents; their ability to express partial ordering of these subcomponents; and to serve as a guide for developing the command and control of semi-revolutionary systems. The CBRNE response system has been analyzed using the GDTA and CWA methods, which encompass all three categories: Goal-driven, Information-driven, and crossover CTA techniques (see Chapter III for GDTA and CWA results).

After the CWA and GDTA were completed, the CIFA technique was applied to the analyses results. The CIFA technique, therefore, is not in itself a CTA technique, but rather it uses the CTA results as its starting point. It may be possible to perform the CIFA technique without first conducting the CWA or GDTA; however, that proof is left as future work. This sub-section addresses the issues presented in each of the three task analysis categories.

Goal-driven CTA techniques focus on goals, tasks, and functions, making these techniques easy to understand, thereby facilitating communication with subject matter experts and designers unfamiliar with CTA techniques. However, goal-driven CTA techniques provide limited mechanisms for partial scheduling or representing parallelism, both of which are of interest in the CBRNE response system. One of the goals in choosing a CTA technique was to assist the designers in developing robotic systems to improve the response. These robotic systems will operate in parallel with the existing CBRNE response and will require an understanding of task and information scheduling.

Furthermore, it is likely that the robots will be used as information providers; therefore, explicit representation of the information, its flow, and its effect on the CBRNE response was necessary in order to understand the impact and the benefit the robotic system will provide. It is for these reasons that goal-driven CTA techniques, by themselves, are not recommended for informing the HRI system design for this domain.

Information-driven CTA techniques were designed to represent the path of information through the system. The two reviewed techniques, CbTA and Visual Dataflow, also allow partial scheduling and representation of parallelism, both of which are of interest in the CBRNE response system. These aforementioned CTA attributes present in information-driven CTA techniques address the outstanding issues with the goal-driven CTA techniques; however, information-driven CTA techniques introduce their own disadvantages. The disadvantages of information-driven CTA techniques are that they deemphasize or ignore goals and they do not directly represent the decision question(s) that form the motivation for tasks.

Crossover CTA techniques are hybrids that combine elements from goal-driven and information-driven CTA techniques. The crossover CTA technique reviewed was the GDTA technique. The GDTA is a goal-driven CTA technique that incorporates information elements via information requirements. These information requirements can be modeled according to different abstraction levels, which can incorporate full dataflow language modeling. As discussed in Chapter II, this approach, proposed by Flach et al. (2004), is really two modeling methods that are loosely coupled. However, the GDTA is primarily a goal-driven CTA technique and when used for the CBRNE response system it became clear that the aforementioned crossover features do not fully mitigate the scheduling and parallelism issues that GDTA inherits from goal-driven CTA.

The issues with the discussed CTA techniques motivated the creation of a new analysis technique that was applied to the GDTA and some of the CWA results (see Chapter III for an overview of the analyses results). The proposed technique is termed Cognitive Information Flow Analysis (CIFA). The CIFA technique is based on the Visual Dataflow technique with a few new features, some of which are borrowed from the GDTA technique. The following sections discuss the components of this new technique, the results of performing the CIFA on the CBRNE example from Chapter III, how the GDTA and CWA techniques compare with the CIFA technique, and the advantages provided by the CIFA technique.

Cognitive Information Flow Analysis Components

CIFA Similarities to Visual Dataflow

The Cognitive Information Flow Analysis (CIFA) technique is based on the Visual Dataflow languages. Like Visual Dataflow, the CIFA is a directed graph with nodes connected by arcs (Dennis & Misunas, 1974). The nodes represent functions that consume information from the incoming arcs; produce new information by transforming, altering, or annotating the consumed information; and distribute the new information onto the outgoing arcs (Figure 24). The CIFA function node, like the Visual Dataflow function node as discussed in Chapter II, is represented by a rectangle with rounded corners. The information passed along the arcs is represented by traditional rectangles (i.e., squared corners). The relationship between the nodes is that of producer-consumer, as it is in Visual Dataflow. The similarities between Visual Dataflow languages and the CIFA are limited to those discussed above.

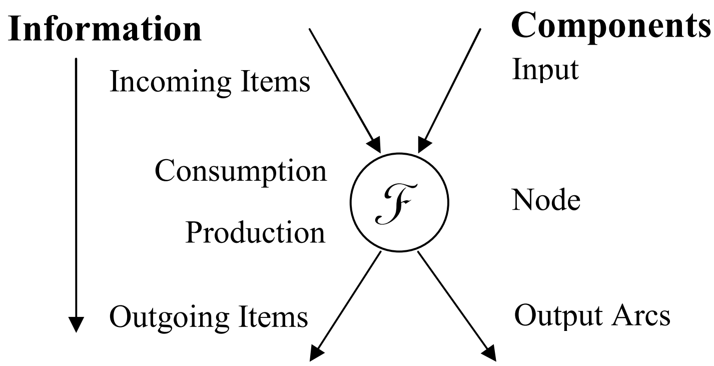


Figure 24: The components of a basic function node.

CIFA New Features

There are three major differences between Visual Dataflow and the CIFA: two modifications to the function node and one change to the linking arcs. The Visual Dataflow function nodes lack an explanation of purpose as the function nodes only express the action and not the motivations for the action, or purpose. The GDTA provides an explanation of purpose very elegantly by including a decision question with each function (Endsley et al., 2003), which is designed to capture the question of why this function is performed (see Figure 9 on page 38). The GDTA decision question feature is included in the CIFA and is added to the function node, as shown in Figure 25. A decision question provides a function node with a goal, or purpose, thereby allowing designers to more freely modify the function's implementation while still ensuring that its purpose is achieved. Since one of the purposes of this research is to extend the CBRNE response system by introducing new robotic technology, decision questions are a useful, necessary component. The new robotic technology will change or add new information items and the inclusion of the decision questions allows designers to determine if the resulting new function compositions adhere to their original purpose as captured in the GDTA decision question.

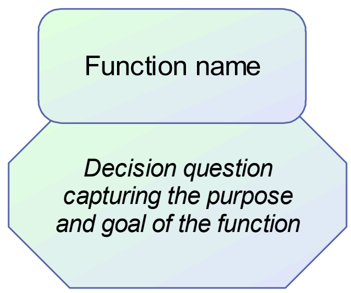


Figure 25: CIFA function node with GDTA style decision question added.

The CIFA technique adds another new feature not present in the techniques previously discussed. This new feature is that of users or User Levels associated with a particular function. Most CTA techniques do not explicitly state what user or User Level is responsible for a particular function because most analyses and techniques are designed for a single user. However, the information regarding who is responsible for which functions is very important for human-based systems such as the CBRNE response system. The CBRNE response system has hundreds, if not thousands, of active users; therefore, the CIFA specifies User Levels rather than individual users. This feature assists with designing the human-robot interfaces for use by the different User Levels, as different users have different information requirements, responsibilities, and system interaction styles. The User Level feature in the CIFA allows the analysis to specify which functions and information items are important for a particular user or user type, thereby facilitating the designer's ability to tailor the interaction with the system to this particular user or User Level.

The addition of user or User Level information is achieved by adding another box to the side of the function nodes, as shown in Figure 26. The function nodes have three components, in contrast to information-driven CTA techniques that typically have only one, or the GDTA that has two. The three components are the function name, the decision question capturing the function's purpose and goal, and the users or User Levels that perform or are involved with the function. The particular User Levels within the CBRNE response system are discussed in Chapter IV.

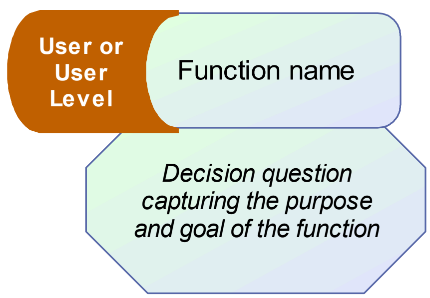


Figure 26: The three components of the CIFA technique's function node, from upper left to lower right; user or User Level, function name, and the decision question.

Another difference between the CIFA and the Visual Dataflow languages is how information is consumed. Visual Dataflow languages have multidimensional extensions that allow for two types of consumption for each incoming arc, which will henceforth be referred to as OR consumption (i.e., One at a time and Required) and MR consumption (i.e., Many at a time and Required). OR consumption occurs when one information item is consumed each time the function is executed, as represented in Figure 7 on page 33 with the "+" function node. In this consumption type, a function can only execute when there is at least one information item queued on the incoming arc. The MR consumption type, in contrast to OR consumption, allows a collection of information items to be consumed or reviewed on the incoming arc when the function is executed, as represented in Figure 8 on page 35 with the average function node. MR consumption allows a function to review the queue or history of a particular incoming arc instead of responding instantaneously to each new information item irrespective of its past. This consumption type is very useful, as it has been shown to handle noisy and incorrect information items better than the OR consumption type (Murthy & E. Lee, 2002). As with the OR consumption type, the MR consumption type must have at least one information item on the incoming arc before it can execute. Both of these consumption types are represented in the CIFA technique. Additionally, the CIFA introduces an additional consumption type.

The new information consumption type was designed to represent the optional input item. When analyzing the CBRNE response system using a preliminary CIFA, it became apparent that some information items were optional and were simply included to help a function refine its information output, when present. With this new type of information consumption, a functional node can execute without waiting for this information item to be present. This information consumption type can be applied to either single OR or MR consumption types and yields two new information consumption types: OO consumption (i.e., One at a time and Optional) and MO consumption (i.e., Many at a time and Optional).

These four information consumption types are represented visually in CIFA by two different line types and two different arrowhead types, as shown in Figure 27. The OR consumption type, one required information item, is represented by a solid line with a single solid arrowhead (Figure 27a). The MR consumption type, a history or review of required information items, is represented by a solid line with a double solid arrowhead (Figure 27b). The OO and MO consumption types, the optional information items, can be applied to either of the first two consumption types and are represented by a dashed line (Figure 27c & d).

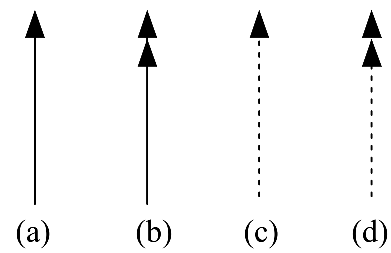


Figure 27: The CIFA information four consumption types: a) OR: one item at a time and required, b) MR: multiple items at a time and required, c) OO: one item at a time, optional, and d) MO: multiple items at a time, optional.

The last added feature does not increase the expressiveness of the CIFA but allows the CIFA to be easily divided into logical sections for clarity. The logical sections were based on the sub areas identified in the WDA results. The biggest modeling issue with dividing the CIFA model into sections is denoting information items that are coming from functions represented in other sections. A double border line signifies when an information item in a section is produced by another section (see Figure 28). The "informing" section is denoted in parenthesis underneath the information item name. For example, in Figure 29 "from Victim Care" means the information item "Victim Awareness" is produced in the CIFA section called Victim Care.

Figure 28: The double border line representing an information item that originates in a different section of the CIFA model.

Cognitive Information Flow Analysis Results

The CBRNE response system was analyzed using two techniques: CWA and GDTA (see Chapter III for results). After the GDTA and CWA were conducted, the results were used to perform the CIFA technique. However, it may be possible to perform the CIFA without first conducting the GDTA or CWA techniques first, but that proof is left as future work.

The CIFA performed on the CTA results of the CBRNE response system resulted in a model containing approximately fifty functions and over 150 information items. As with the other methods, the CIFA results were broken into four logical sections to facilitate discussions. Those sections are Emergency Evaluation, Incident & Hazard Mitigation, Victim Care, and Command and Information Management. As with GDTA and CWA results in Chapter III, only the results regarding Emergency Evaluation are presented and discussed in this chapter. The remainder of the results is provided in Appendix C.

The CIFA model of the Emergency Evaluation section contains thirteen functions, fifty-two information items, and eight different User Levels (Figure 29). The overall goal of Emergency Evaluation is the top most function "Life Safety Assessment" and is defined by the decision question, “What is the assessment with regards to Health and Hazards of this incident?” and produces the “Life Safety Assessment Report.”

The Emergency Evaluation model employs all four consumption types as demonstrated by the “Collection of hazard information” function in the bottom left of Figure 29. The “Types of symptoms (or lack thereof)” information item employs the MR consumption type. The three vertically placed information items to the left (i.e., “Hazard description information,” “Hazard behavior information,” and “Hazard locations and dispersion”) employ the OR consumption type. The two vertically placed information items (i.e., “Hazardous materials samples” and “Technical Decontamination Status”) below the “Hazard locations and dispersion” information item are connected by OO consumption. The six vertically placed information items on the far left (i.e., “Hazard detection equipment readings,” “Toxic industrial chemical detection readings,” “Background radiation levels,” “Radiation meters,” “Images (photo and video),” and “Air monitoring devices”) employ MO consumption. Thus, to produce the “Hazard Reading Report” from the function “Collection of hazard information”, the following information items are required: “Types of symptoms (or lack thereof),” “Hazard description information,” “Hazard behavior information,” and “Hazard locations and dispersion”, while the remainder of the information items are considered optional. These four required information items encompass the basics of *what* (i.e., types of symptoms (or lack thereof), hazard description information), *where* (i.e., hazard locations and dispersion), and *what is this hazard going to affect* (i.e., hazard description information, hazard behavior information). The other eight information items simply refine and improve the “Hazard Reading Report.” This breakdown of information items based on their consumption types complements the subject matter experts' feedback regarding the "Collection of hazard information" function in that this function begins producing results at the very beginning of the incident when information is scarce.

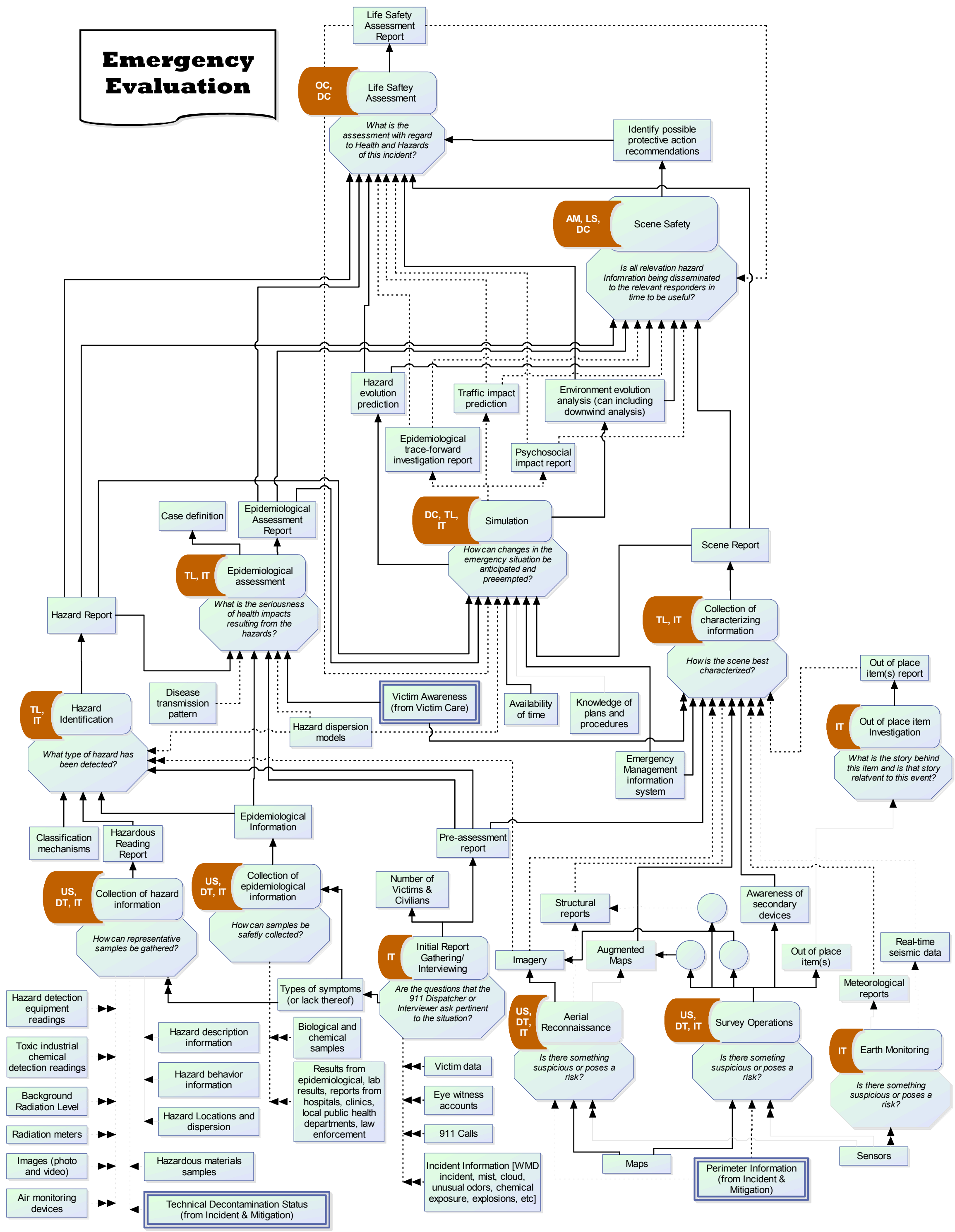


Figure 29: The CIFA of the CBRNE response system Emergency Evaluation section.

Comparing GDTA, CWA, and CIFA

The CIFA was developed to combine the GDTA and CWA results based on their different perspectives into a single representation that facilitates system design and, in particular, system visualization design. The CIFA has five major elements, which will be compared with the GDTA and CWA techniques. These elements are functions, information items, user or User Levels, decision questions that capture goals and purposes, and interconnections between the functions. This section compares the analysis methods in detail.

Comparing GDTA and CIFA

The GDTA, if it is a two level analysis, has six components: the overall goal, level 1 sub-goals, level 1 decision questions, level 2 sub-goals, level 2 decision questions, and level 2 information requirements, also called situational awareness requirements (Endsley et al. 2003). The overall GDTA goal does not translate into a CIFA component, which is one disadvantage of the CIFA.

The GDTA's lowest level sub-goals, those directly associated with information requirements, can translate into CIFA functions in several different ways for two reasons. The first reason is the different relationships used in the two analysis methods, that is, GDTA's part-whole relationship and CIFA's producer-consumer relationship. The second reason is that the CIFA is also based on the mCWA, which influenced the composition of CIFA functions. The GDTA's decision questions translate almost directly when the corresponding GDTA function corresponds to a CIFA function. GDTA sub-goals translate into CIFA directly, by decomposition and in combination.

A direct translation occurs when a GDTA sub-goal's concept maintains the same representation in the CIFA. For example, the GDTA sub-goal “2.3 On Scene Health and Hazard Assessment” has six sub-goals (see Figure 15). The sub-goals, “2.3.1 Collect Characterizing Information” and “2.3.2 Collect Hazard Information”, translate directly into CIFA Emergency Evaluation functions (Figure 29, bottom left and middle right respectfully). However, the remaining four sub-goals do not directly transfer.

A translation by decomposition occurs when a GDTA sub-goal is split into two or more CIFA functions. For example, the GDTA sub-goal “2.3.3 Assessment” is decomposed into two CIFA functions: “Hazard Identification” and “Epidemiological Assessment” (Figure 29, middle left edge and middle left respectively). This decomposition was inspired by the WDA results, which separates hazards that have discreet physical locations (e.g., bombs, chemical spills) from those that are airborne or otherwise mobile (e.g., diseases, chemical clouds).

A combination translation occurs when two or more GDTA sub-goals are merged into one CIFA function. For example, the sub-goals “2.3.4 Epidemiological Trace-Forward Investigation” and “2.3.5 Situation Status Report” are combined into the CIFA function “Simulation” (Figure 29, center). However, some of the corresponding information requirements of sub-goal “2.3.4 Epidemiological Trace-Forward Investigation” and a portion of its decision question became elements of the “Epidemiological Assessment” CIFA function instead of elements in the “Simulation”

CIFA function. This splitting of the sub-goal occurred because of its dual nature, one element being the epidemiological assessment and the other element that performs the trace-forward analysis (i.e., a simulation).

There are some GDTA sub-goals that are not represented by CIFA functions. Their absence does not mean that they cannot or do not translate into CIFA functions, but that they have not been translated for various reasons. For example, the GDTA sub-goal "2.3.6 Archive Data" is not explicitly represented by a CIFA function since it is implicitly contained within all other CIFA functions: all data can be archived.

The high-level sub-goals, those without their own information requirements, do not translate directly into the CIFA due to the GDTA's part-whole relationship. Since CIFA does not use the part-whole relationship and the GDTA's components (i.e., low-level sub-goals) are, at least partially, represented in CIFA, the high-level sub-goals are not translated. The high-level sub-goals from the GDTA are represented only in the CIFA if they embody a concept that is more than the sum of the parts. For example, the GDTA sub-goal "2.3 On Scene Health and Hazard Assessment" is a high-level sub-goal and translates into the CIFA function "Life Safety Assessment" (Figure 29 center top) because it fuses the sub-goals' results into a meaningful item that is expressed to higher level goals.

The translation from the GDTA into the CIFA is not simple and, as with the WDA, CIFA is informed by the GDTA rather than representing a direct translation of the GDTA's results. Almost all of the GDTA's information requirements are represented in CIFA, with many translating directly. However, the GDTA information items often become refined information items when incorporated into the CIFA. This refinement occurs because some GDTA information items are merged, subsumed, or replaced in CIFA. CIFA refines the information items by clearly representing which information items are produced by functions and represents an information item as a single entity regardless of how many functions use it. The GDTA typically duplicates an information item for each function that uses the information item across the analysis. For example the GDTA information item “0031 Change conditions at incident site” is duplicated for each sub-goal of 2.3 (Figure 15).

Various methods have been employed to clarify the GDTA when one information item is used by many functions. One method is to maintain the exact same wording; however, if different functions are created from different documents or from feedback from different sets of subject matter experts (i.e., police vs. fire personnel), the wording is often similar but not identical, leaving the designer to determine if the information items are the same information item or similar yet different items. Another method of clarifying information items is a call out box that lists a number of information items that can be grouped, as was done in the Adams et al. (2008) analysis of the wilderness search and rescue response system, as shown in Figure 30. While this method works, it is appropriate only when the collection of information items can function as a logical unit.

Figure 30: A call out box for information items used the GDTA model presented in Goodrich et al. (2007). This collection of information items is then collectively referred to as "Environment."

A third method of clarifying related GDTA information items is to assign each information item a unique number (Humphrey and Adams 2008). This method adds precision that indicates which information items are the same regardless of any variation in the text, but this solution is not as elegant or clear as the CIFA's method. This lack of elegance and clarity exists in the GDTA because a designer must physically scan all sub-goals in order to identify all instances in which an information item is used. Returning to the previous example, information item 0031 is identified for all sub-goals of "2.3 On Scene Health and Hazard Assessment," but its existence is not obvious until one scans through all the sub-goals in Figure 15. CIFA handles this situation via the visual arrows leading from the information item to all functions using that item. For example, the information item "Pre-assessment report" (horizontally centered in the lower middle of Figure 29) has three arrows leading from it to the three functions that use this information item, thereby reducing visual scanning. The arrows can provide clarity and certainty not matched by any of the described GDTA representations.

The relationship between the GDTA and the CIFA is one where most of the GDTA elements translate into the CIFA model; however, the CIFA model contains elements and features that are not present in the GDTA. Many of the information items present in the CIFA are not represented in the GDTA. There are two primary reasons that the GDTA does not represent all of CIFA information items: the GDTA generally does not represent information items produced by a goal and the CIFA draws some information items from the CWA. The GDTA does list some produced information items, such as the item “Results from 2.3.2 collect characterizing information” listed in “2.3.3 Assessment” and this item is translated into the CIFA as “Scene Report” (Figure 29 middle right edge). However, there are other CIFA information items, such as “Life Safety Assessment” (Figure 29 middle top edge) that are the products of the “Life Safety Assessment” function, which has no direct GDTA equivalent. The GDTA does have two information items termed “Reports from field operations” and “Incident Report” listed in “3.1.1 Direct and Control Response Operations” (

Appendix A) that are somewhat related to “Life Safety Assessment.” However, unlike the CIFA, the GDTA does not capture where or how these two information items are produced, making their relationship to CIFA’s “Life Safety Assessment” information item unclear. The information item “Life Safety Assessment” was formulated by using information from the original documents and from subject matter experts.

The CIFA representation of users or User Levels is also not present in the GDTA. The GDTA technique can be extended, as discussed in Chapter III, to include a “people or groups” section along with information requirements, but this extension is not part of the original description (Endsley et al., 2003). The “people or groups” section is still not the same as User Levels that are in the CIFA as depicted in Figure 30. User levels are an abstraction from the GDTA’s people and groups where a User Level represents many different people and groups that share similar responsibilities when viewed from a particular viewpoint, such as their relationship to the robotic system. Finally, the interconnectivity of the CIFA’s functions is not directly derived from the GDTA because the interconnectivity of the CIFA functions is based on the producer-consumer relationship. The interconnectivity of the GDTA functions is based on a part-whole relationship.

Overall, the GDTA directly informed 63% of the functions and 78% of the information items of the CBRNE domain CIFA . Of the GDTA top-level sub-goals represented in the CIFA, all but one sub-sub goal has one or more corresponding CIFA function. Furthermore, over 98% of the information requirements captured in the GDTA are represented in the CIFA. The only information requirements not represented in the CIFA are related to the sub-goal “2.3.6 Archive Data” which was not explicitly included.

Comparing CWA and CIFA

The CWA is a collection of methods, whereas the CIFA is a single method. All of the CWA methods conducted for the CBRNE response system, as presented in Chapter III, had an effect on the CIFA because they were performed prior to and by the same researcher who performed the CIFA. However, only one CWA method was directly employed and referenced during the construction of the CIFA, the Work Domain Analysis (WDA).

The WDA, as used in analyzing the CBRNE response system, has five vertical axis levels: goal, abstract functions, general functions, processes, and object. The WDA's abstract functions, general functions, and processes translate into either CIFA information items or functions. The reason these three levels do not translate into either information items and functions is due to the fact that the CIFA and the WDA employ different modeling perspectives. The WDA represents the work domain while CIFA represents the information flow through the functions. The translation from the WDA to the CIFA is not straightforward because of these differing perspectives.

The WDA provides material, but the CIFA is not a functional translation of the WDA. The direct mapping from the WDA to CIFA is depicted for the Emergency Evaluation subsystem and is depicted in Figure 31. The black square corner boxes in Figure 31 represent the subsystems and functional units of the Emergency Evaluation System captured in the WDA model, as depicted fully in Figure 19. The black square corner boxes in Figure 31 represent WDA elements that became CIFA information items, while the black rounded corner boxes represent WDA elements that became CIFA functions

The WDA's object level items became CIFA information items, where appropriate. A WDA object can represent information either in a physical sense (e.g., reports, maps, images) or as a thing (e.g., ambulance, supplies). If the object represents information, such as maps, then it translates directly into an information item. If the object represents a thing, then it translates into a CIFA information item representing the knowledge of the item or information the item produces, but not the item itself. For example, an object such as "hazard detection equipment" (see lower right corner object "j" in Figure 31) is represented as an information item termed the "hazard detection equipment readings" (see lower left corner in Figure 29).

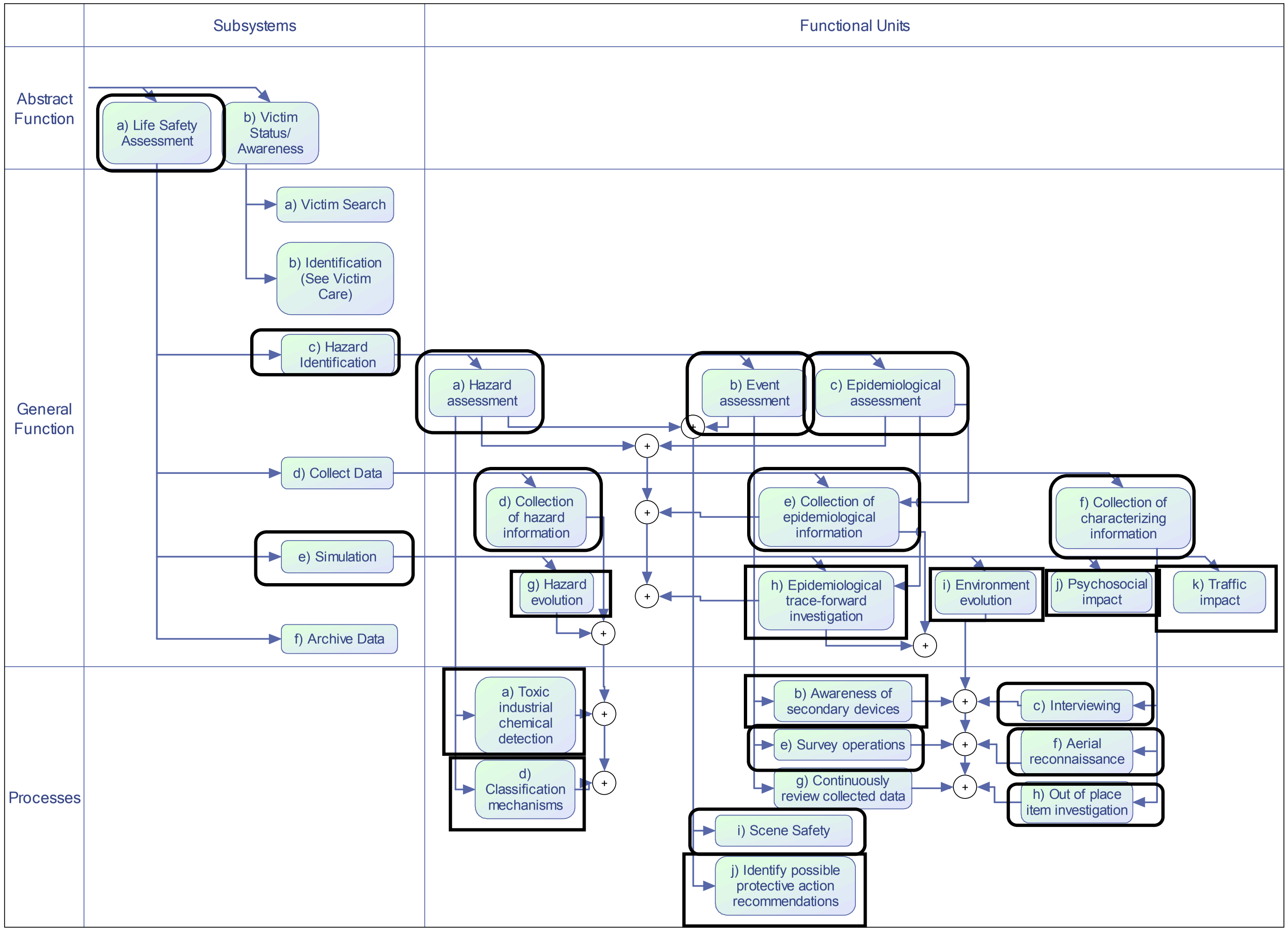


Figure 31: The WDA of Emergency Evaluation with indications of the translation to the CIFA. The black square corner boxes represent elements from the WDA that become information items in the CIFA and the black rounded corner boxes represent elements that become functions.

The interconnectivity captured in the WDA model does not translate into the CIFA model in part because the represented relationships are quite different. As discussed in Chapter II, the WDA uses part-whole and means-end relationships whereas the CIFA uses a producer-consumer relationship.

The relationship between the WDA and the CIFA is one where the WDA elements mostly translate to, or are subsumed by, the CIFA; however, the CIFA contains elements and features not present in the WDA. These additional elements are the result of incorporating the results of both the WDA *and* the GDTA. Most of the decision questions present in the CIFA are not represented in the WDA, but are instead represented in the GDTA.

Many of the CIFA information items are not represented in the WDA. There are two primary reasons the WDA does not represent all of CIFA information items: the WDA does not represent information items directly, and the CIFA draws many information items from the GDTA. The WDA represents information items indirectly through objects, meaning that the WDA lists an object such as "hazard detection equipment" (Figure 19), whereas the CIFA lists the information produced by the object such as "hazard detection equipment readings" (Figure 29). The WDA provides information items indirectly and therefore does not capture all information item types that can be represented in the CIFA, especially the transformation of information items by non-objects, such as humans. For example, the "Scene Report" CIFA information item is produced by the function "Collection of characterizing information" (see Figure 29 middle right side). The WDA also contains a "Collection of characterizing information" item; however, this item has no representation for what is produced by this element (Figure 31: in the Function Units by General Function cell on the right side).

The CIFA function node represents users or user levels as a subcomponent. The WDA does not represent users or user levels; however, the mCWA does include an analysis of relevant social groups and the development of a communication flow map that can identify users and User Levels (see Chapter IV). These methods had a direct influence on the creation and definition of the User Levels that represent the users and User Levels in the CIFA. For example, all of the User Levels' real roles were translated from mCWA's relevant social groups while the separation of the users into user levels draws heavily from the hierarchal structure captured in the mCWA's communication flow map.

Finally, the interconnectivity of the CIFA's functions has similarities and differences to the mCWA's CbTA. The CbTAemploys a two-step action-knowledge structure that generally represents paths that flow from a knowledge state to an action node and then repeats. Similarly, the CIFA represents paths that flow from an information item to a function node and then repeats. However, CbTAand CIFA differ in the meaning represented by the paths and in the type of data represented by their respective knowledge or information nodes. The CbTA's paths link the current knowledge state to the action to be performed to the next resulting state of knowledge. For example, if the current state is the knowledge node, "need to defuse bomb," then the path may link to the action to be performed "defuse bomb" to the resulting knowledge state of "bomb defused." The CbTApaths have a very different meaning from the CIFA paths. The CIFA paths link functions to both the information items used in the function's execution and the information items produced as the result of a function's execution. For example, if the function node is "defuse bomb" then the input information item may be "the type of bomb" and the resulting information item may be "bomb defuse status." CIFA allows its data nodes to represent any type of information, whereas the CbTAonly allows its data nodes to represent states of knowledge. A state of knowledge can easily be composed of many information items, meaning that the CIFA inherently provides more information details.

The CBRNE CbTAresults are not used explicitly in the creation of the CBRNE CIFA because the information represented in the CIFA and the meaning of the paths (i.e., OR, OO, MR, and MO) are different. There are some correlations between the CbTAand the CIFA; however, these correlations are artifacts of representing the same domain and not because the CBRNE CbTAinformed the CIFA. The parallelism and partial ordering that were important factors in employing Statecharts, rather than dDcision Ladders for the CbTA (see Chapter III), are captured in the CIFA since the CIFA is based on Visual Dataflow. Parallelism is represented in the CIFA since the represented functions can execute as soon as they have all of their required information items without regard to other functions; that is, multiple functions can execute concurrently. The CIFA represents partial ordering through the production of information items: functions that rely on other functions being performed first are blocked from executing until the required functions produce the needed information items. Therefore, the parallelism and partial ordering represented by Statecharts for CbTAare represented in the CIFA.

Overall, the mCWA's WDA directly informed 88% of the functions and 30% of the information items of the CBRNE domain CIFA . It should be noted that the presented percentages and the corresponding percentages in the GDTA comparison section exceed 100% due to an overlap of some of the GDTA and mCWA results. The WDA systems represented in the CIFA have all their sub-systems at the abstract function level represented in the CIFA. The CIFA's User Levels were partially informed by the mCWA analysis of global, organizational, and ethical factors methods.

Informing Human-Robotic Interaction Design

The CIFA is useful in Human-Robotic Interaction (HRI) interface design for informing what types of information need to be presented and how these information items may be represented and abstracted. However, the CIFA, like the mCWA and GDTA, does not support informing the user interface component layout.

The CIFA informs the information types that users require during a specific function or task by capturing the information items to be consumed by that function and the type(s) of consumption involved (i.e., MO, MR, OO, OR). In other words, the CIFA informs what information items are to be used and how they will be used for performing particular tasks.

Due to the extensiveness of the CBRNE domain, there may be many information items presented in an interface visualization, which may lead to clutter and cognitive overload. Therefore, the information items need to be abstracted or managed in order to be presented in a more organized manner. The CIFA identifies how different information items relate to each other and can assist in transforming, or abstracting, the information items into a single, more coherent information item.

For example, when the team leader User Level performs the CIFA function "Hazard Identification" (Figure 29, left side), he or she does not necessarily view all available information items that a robot specialist may view, as in Figure 32a. The CIFA provides a filter and abstracts the information items necessary to support the "Hazard Identification" function by specifying which information items are used or consumed and which items are irrelevant. For example, the "Hazard Identification" function consumes the "Hazardous Reading Report"; therefore, the individual hazard readings can be combined and abstracted into reports (Figure 32b). Furthermore, the "Hazard Identification" function does not require individual victim information; rather it relies on an abstract representation of victim symptoms, severity of injuries, and locations. This can be represented by area gradients, such as light red for areas with limited victim injuries and darker red for more serve victim injuries (Figure 32b). Other items such as robot and responder locations and structural reports can be removed as those items are used by other functions. Thus, using the CIFA, the visualization can organize the information presented in Figure 32a into the visualization presented in Figure 32b.

(a) (b)

Figure 32: Two visualizations of information items: (a) the items are unorganized, and (b) the items are filtered and merged based on the CIFA results to support the hazard identification task.

Secondly, according to the current function or User Level, the CIFA can provide the relative importance of information items, thereby assisting in determining their representation. For example, if the operations chief User Level is viewing the visualization, individual victim injuries (Figure 32a) can be displayed less saliently or not at all (Figure 32b), as the operations chief is not involved with a CIFA function that directly uses individual victim injuries.

CIFA Advantages

The use of the CIFA in analyzing the CBRNE response system has highlighted a number of advantages of this technique, including focus or perspective, identification of information bottlenecks, highlighting of teamwork, and ease of translation into prototyping. The focus advantage is primarily based on the flow of information; however, unlike the CbTA, which was similarly based on the flow of knowledge states, the CIFA provides greater expressiveness because it models all types of information and can express different means of consuming the information. The focus on information highlights the SA requirements for each and every function, which has been proven important for human-robotic interaction (Drury et al., 2003; Scholtz et al., 2005; Yanco & Drury, 2004).

The GDTA also focuses on SA requirements; however, the GDTA's presentation is not as crisp as that provided by the CIFA, nor does the GDTA's presentation express how functions transform information as clearly as the CIFA's presentation. For example, the CIFA clearly represents that the "Hazardous Reading Report" is produced from the "Collection of hazard information" function by consuming or using four to twelve information items. It can be argued that when the GDTA includes the extensions from Flach et al. (2004) (i.e., information requirement represented in an abstraction decomposition), the GDTA has as much expressive power as the CIFA. However, these extensions do not achieve this expressive power through a single model diagram but a collection, whereas the CIFA is a single unified model diagram.

Another advantage of the CIFA is the ability to pinpoint information bottlenecks in terms of both particular functions and particular users. An *information bottleneck* is defined as a point in the system where a greater than average number of subsequent functions cannot be executed without the information from this point being provided. An information bottleneck is defined mathematically as the number of functions that require a particular information item over the average number of functions that require any particular information item. The identification of information bottlenecks becomes critically important in interaction design, as these identified information items are most important to the users and therefore may need to be treated differently in the design. The information item “Pre-assessment report” in Figure 29 (center and towards the bottom) is an information bottleneck as three important functions require information from it and those functions’ outputs are subsequently required for many other functions. The identification of this information item as a bottleneck correlates with subject matter experts reports that the “Pre-assessment report” is one of the very first pieces of information that is developed and many early response decisions are based on that report. When designing new systems, these information bottlenecks can be critical spots where human-robotic systems may improve or worsen the information flow and thereby greatly affect the overall CBRNE response system.

The CIFA’s focus on the information flow through functions facilitates HRI design. The identification of the required input and output information (i.e., information flow) is crucially important for any given function to be performed or directed through the interface between humans and robots. Prior research has demonstrated that input information (i.e., situation awareness) is important to HRI (Drury et al., 2003; Scholtz et al., 2005; Yanco & Drury, 2004). Output information subsequently becomes input information for other functions; therefore, by extension, output information is important to HRI. The CIFA technique can express all of the input and output information succinctly and clearly, thereby supporting HRI design.

The advantage of CIFA in highlighting teamwork is a direct consequence of its incorporation of identified users or user levels for each function. If a function has more than one user associated with it, there is a strong potential that these users are either part of a team or may benefit from being part of a team. This advantage is especially useful in new domains since it can identify how new functions could be performed through teamwork.

Limitations

The only discovered limitation of the CIFA employed for the CBRNE domain is that it was informed by the results of the GDTA and CWA. Therefore, as performed for the CBRNE domain, the CIFA required the two CTA techniques to be performed first, which greatly adds to the time and complexity of analyzing a domain. However, the design of the CIFA technique does not include any constraints that should limit its application to domains that have not first performed a CTA.

Summary

The Cognitive Information Flow Analysis (CIFA) technique has been developed to analyze the information flow throughout a system. The CIFA, in this case, has been developed based on the results of the GDTA and CWA. The GDTA and CWA models do not directly translate into the CIFA model, but both heavily inform the resulting CIFA model. The GDTA and CWA inform, rather than directly translate into, the CIFA because the CIFA views the system from a different perspective. Just as a CWA cannot directly translate into a GDTA, both the GDTA and CWA do not directly translate into the CIFA. The CIFA may be performed without first conducting a GDTA or a CWA;

however, the proof of such CIFA will be left as future work. The CIFA was designed to analyze revolutionary and semi-revolutionary systems; whether it is applicable to other domains is left for future work.

The CIFA has a number of abilities and advantages. The ability to express the interconnectivity of the various system subcomponents with an elegant focus on the flow of information items is its most fundamental characteristic. The CIFA also expresses partial orderings of these subcomponents via their relationship within the flow of information. The focus on the information flow provides the ability to identify information bottlenecks. The addition of users or User Levels provides the ability to highlight teamwork, both current and potential. Finally, the CIFA serves as a guide to developing the command and control of semi-revolutionary systems, which will be discussed further in subsequent chapters.

CHAPTER VI

VISUALIZING THE SYSTEM

These proposed robotic technologies for the CBRNE response system will use computer-based visualization for both command and control of the robots, and to provide feedback from the robots. The goals of the visualization are to present the information in a manner that supports decision making at different User Levels, supports communication between different User Levels, and allows the hierarchy of decision-makers to recall past information. Supporting these decision-makers requires that three problem areas be addressed: information abstraction and presentation, relaying information to the different User Levels, and temporal navigation. This research proposes the General Visualization Abstraction (GVA) algorithm to address the information abstraction and presentation problem area. The relaying of information to different User Levels is addressed by the introduction of the Decision Information Abstracted to a Relevant Encapsulation (DIARE) object concept. The last problem area, temporal navigation, is partially addressed by using the results of the GVA algorithm and DIARE to index time, thereby assisting temporal navigation. This chapter presents the GVA algorithm, the DIARE object, and temporal navigation concepts.

General Visualization Abstraction (GVA) algorithm

Abstraction is critical to decision making as its absence means that the decision-maker must manually parse the important information from the unimportant information and manually group related information. Both of these tasks, parsing and grouping, are cognitively demanding (Wickens et al., 2003). Furthermore in multi-scale visualizations, abstraction is important as some information details cannot be represented at a particular scale due to limitations in screen size without abstraction. Information abstraction involves three operations that are preformed on the information items; selection, grouping, and representation. The relevancy feature of effective incident management visualizations is usually addressed through selection (Cai et al., 2006).

The basic information unit in a directable map-based visualization is an *information item*, which has two components: location (if it is a single point) or location range (if it is a polygon), and meaning (m). The location has five dimensions (5D): latitude (x), longitude (y), elevation (e), time (t), and information scale (s). An information item can, therefore, be represented mathematically as a sextuplet [x, y, e, t, s, m] where each of the values in the sextuplet can be a single value (e.g., elevation of 10 meters) or a range of values (e.g., from 13:15 to 15:47). The problem is how to abstract information that has spatial, temporal, information scale, and semantic meaning in order to reduce clutter, thereby providing a relevant visualization for on-demand decision making. A solution that uses all of the available information components and is appropriate for novel information and unanticipated decision-making will advance the field and provide a foundation on which subsequent work in information abstraction can be built.

The CBRNE response system directable visualization employs a novel algorithm, called the General Visualization Abstraction (GVA) algorithm that performs information abstraction (i.e., selection and grouping) and determines how each information item is to be presented (i.e., its shape).

GVA algorithm

The GVA algorithm produces a *visual score* (v) for each information item to determine if it will be displayed, if it should be grouped with others, and its representation state. The visual score represents how important displaying a particular information item is to the decision-maker given a certain context and is a continuous value.

The GVA algorithm uses this visual score to determine an information item's representation and whether the item should be considered a candidate for grouping (i.e., clustering). The GVA algorithm only indicates in which visual state an information item should be represented; it does *not* provide that actual graphical representation. An information item may be displayed in one of four visual states: high details, normal, residue, or not displayed (see Figure 33). An information item presented as *residue* provides evidence that leads the user to understand that additional details are available by taking a clearly indicated action (Jul & George W. Furnas, 1998).

(a) (b) (c)

Figure 33: An example of the three visible information item visual states a) high detail, b) normal, and c) residue.

Information items are candidates for grouping if their visual scores are too low to be displayed in high details, but high enough to be displayed as residue. An information item presented as *residue* provides evidence that leads the user to understand that additional details are available by taking a clearly indicated action, such as hovering the cursor over the item (Jul & George W. Furnas, 1998). If the information item candidates for grouping are close geographically and logically, then they are grouped. If the information items are not close in either respect, then they are displayed as their visual score dictates.

The GVA algorithm's presentation method is similar in concept to the Focus plus Context visualization technique (Baudisch et al., 2002). The Focus plus Context visualization has two screen areas: a focus area where information is presented in high details, and a surrounding context area where information is presented in fewer details. The GVA algorithm applies this concept not to the screen, but to the information items themselves. Information items that are considered important or in focus (i.e., have a high visual score) are presented in high or normal details; whereas, information items that are not as important (i.e., have a low visual score) are presented in fewer details or residue.

Algorithm 1 expresses the general approach the GVA algorithm uses to select, group, and display information items as outlined above.

Algorithm 1: The GVA algorithm method to select, group, and display information items.

For each time step:
For each information item, i
Compute: the item's visual score, v_i

For each information item, i, that is displayed (i.e., $v_i \geq v_{residue}$)
If $v_i \geq v_{details}$ $v_i \geq$
If any of its displayed neighbors are logically similar
Then group the item, i, with these neighbors
Else
Then display the item, i, in full details.
Else If $v_i \geq v_{normal}$ $v_i \geq v_{low}$
Then display the item, i, in normal details.
Else If $v_i \geq v_{residue}$
Then display the item, i, as residue.
Else $v_{details}$
The item, i, is not displayed

Where:
$v_{details}$ $v_{details}$ is the minimum visual score required for an item to be displayed in full details.
v_{normal} is the minimum visual score required for an item to be displayed in low details.
$v_{residue}$ is the minimum visual score required for an item to be displayed as residue.

The Visual Score

The GVA algorithm calculates each information item's visual score (v) by evaluating how strongly an item belongs in one of two information classes. The first information class focuses on if and how the user has interacted with the information item (i.e., how historically or currently relevant is this information item). The second information class focuses on information item aspects not related to user interaction (i.e., is the information item novel or emerging). These two information classes are designed to balance the user's focus of attention (i.e., historically and currently relevant information) with other possibly important but overlooked information (i.e., novel and emerging information). However, an algorithm that does not consider factors other than the item's association with either information class is limited. Therefore, two additional factors provide robustness: predetermined importance and an item's contribution to the overall visual clutter.

The *predetermined importance* factor is added to express knowledge known a priori by the system designer regarding the inherent importance of certain information items above or below the average or generic information item (e.g., active bombs are very important). Therefore, predetermined importance is an offset that can raise or lower the visual score but will have no effect if predetermined importance is unavailable for the information item.

The concept of visual clutter provides a balance between displaying all possibly useful information and displaying so much information that the screen becomes visually cluttered. *Visual clutter* is the condition when the density of information displayed on the screen is greater than some optimal level, resulting in a breaking of the constant information density principle (Woodruff et al., 1998). *Constant information density* is the principle that if the amount of information displayed is greater than some threshold, then displaying more information degrades the performance and effectiveness of the system. When information is too dense it is considered cluttered. The GVA algorithm's clutter factor directly addresses this concern.

The visual score (v) is expressed in Equation 1 as a composition of the two aforementioned factors, predetermined importance and clutter, and the item's association with the two information classes. Each component of the equation is denoted with square brackets (i.e., [ ]) and constants are added to scale the components' relative contributions to the visual score.

Equation 1: The six components of the GVA algorithm's visual score calculation.

$$v = \mathrm{k}_1[\mathit{Predetermined\ Importance}] - \mathrm{k}_2[\mathit{Clutter}] + \max\{\mathrm{k}_3[\text{Historically Relevant}] + \mathrm{k}_4[\text{Currently Relevant}],\ \mathrm{k}_5[\text{Novel}] + \mathrm{k}_6[\text{Emerging}]\}$$

Where:

$\mathrm{k_n}, \mathrm{n} = 1, 2, \ldots$ are scalar constants used to determine the relative importance of each factor.

[ ] represents a component that returns a value in the range from -1 to 1.

The two information classes are designed to balance or compete with each other in order to determine the visual score and are therefore combined in Equation 1 via a max function. If the information classes were summed, they would be cooperating. Cooperation is not desired because in a cooperative situation low historically and currently relevant values will negatively impact the display of novel or emerging information; whereas, if the two classes compete the low historically and currently relevant values are simply ignored and the information item is displayed based purely on the novel and emerging values. Only through competition can the two information classes meet their objective of balancing the user's focus with other possibly important, but overlooked information.

Relation to Common Approaches

Two other common approaches to the selection problem, domain specific heuristics (Jul & George W. Furnas, 1998; Cai et al., 2006; Ward, 2002) and random sampling (Ellis & Dix, 2006) techniques, discussed in Chapter II can be expressed as subsets of Equation 1. Expressing the domain specific heuristic approach requires that the constants k_2 to k_6 are set to zero, thereby enabling only the predetermined importance. Based on the domain specific heuristic version of Equation 1 (i.e., Equation 2), it becomes evident that the visual scores become meaningless when there are many unknown items (i.e., with a predetermined importance of zero) because all items will have the same visual score leading to no improvement in information abstraction and clutter reduction.

Equation 2: The domain specific heuristic version of Equation 1.

$$v = \mathrm{k}_1[\mathit{Predetermined\ Importance}] \cancel{- \mathrm{k}_2[\mathit{Clutter}] + \max\{\mathrm{k}_3[\text{Historically Relevant}] + \mathrm{k}_4[\text{Currently Relevant}],\ \mathrm{k}_5[\text{Novel}] + \mathrm{k}_6[\text{Emerging}]\}}$$

Where *k_n, n* = 1, 2, etc. represent scalar constants representing each factor's relative importance.

The random sampling approach (Ellis & Dix, 2006) uses only the clutter factor, to select randomly some information items based on the notion of the constant information density concept (Woodruff et al., 1998). The random sampling approach can be represented in Equation 1 by setting all constants except k_2 to a zero value, as random sampling is based solely on the clutter factor (see Equation 3). The random sampling approach is limiting because it is incapable of assigning values to information items that are more important, by any metric, than other items. Therefore, the random sampling approach is only appropriate when all information items always have the same value. This situation is improbable when the visualization is representing a dynamic real-time, real-world system (e.g., CBRNE incident response).

Equation 3: The random sampling version of Equation 1.

$v =$
~~$k_1[\mathit{Predetermined\ Importance}] -$~~ $k_2[\mathit{Clutter}] +$
~~$\max\{k_3[\text{Historically Relevant}] + k_4[\text{Currently Relevant}],\ k_5[\text{Novel}] + k_6[\text{Emerging}]\}$~~

Where k_n, n = 1, 2, etc. represent scalar constants representing each factor's relative importance.

The domain specific heuristic approach can also degrade into the random sampling approach if the information item has no predetermined importance value, which occurs when the information item is unanticipated by the visualization designer. It is possible that after some time the operator will assign an importance value to the unanticipated information item; however, this approach relies on the operator making wise choices and is static with regard to time.

Two factors common among other approaches are the predetermined importance and clutter factors; however, the other four factors, historically relevant, currently relevant, novel, and emerging, are not and it is the inclusion of these factors that sets the GVA algorithm apart from other approaches. The GVA algorithm is designed to address the information abstraction problem in an intelligent manner, even when there are unanticipated non-uniformly valued information items, by utilizing all six components in Equation 1, particularly the last four factors.

The Six Visual Score Components

The actual equations to compute the six components can vary depending on the program employing the GVA algorithm, providing the equations meet a few constraints. The visual score equation is designed for each component to be a continuous value from zero to one. The exception is the predetermined importance component, which ranges from negative one to positive one with zero being the default value when the information item does not have a predetermined importance. The predetermined importance component is different in order to accommodate information items that do not have a predetermined importance. In this case, the item's visual score is neither increased nor decreased. This specification of the predetermined importance ensures that information items without a predetermined importance have no negative effect on the item's visual score.

Although the actual equations for the GVA algorithm's six components are not part of its specification, the following sections will provide details to illustrate how, algorithmically, the components can be measured and computed to yield the visual score. The six components are predetermined importance, clutter, historically relevant, currently relevant, novel, and emerging. Before developing the details as to how to compute each factor, the element m_i, or meaning in the information item's sextuplet, [x, y, e, t, s, m], needs to be revisited. The meaning of an information item can be considered to have two elements: a collection of information types or classes to which it belongs and a particular value. For example, the information item, an undetonated bomb, can be in the class "bomb" with the value being "undetonated". This separation of meaning into two components is used in the computation of several of the factors.

The Predetermined Importance Component

The *predetermined importance* component in Equation 1 can be computed as a simple lookup table based on the meaning of the information item (see Algorithm 2). The meaning of an information item can be considered to have two elements: a collection of information types or classes to which it belongs and a particular value. For example, the information item, an undetonated bomb, can be in the class "bomb" with the value being "undetonated." If the information item's information type is not present in the lookup table, then this item does not have a predetermined importance and the component value is set to zero. As a result, this component has no effect on the information item's visual score.

Algorithm 2: The calculation of Predetermine Importance.

If information item's, i, meaning, m_i, is in the lookup table
  $[Predetermined\ Importance_i] = \text{LookupTableValue}(m_i)$
  Where the function $\text{LookupTableValue}(m_i)$ returns a value from -1 to +1 depending on the predetermined importance of m_i.
Else
  $[Predetermined\ Importance_i] = 0$

The Clutter Component

Equation 1's *clutter* component is calculated from the percentage of the screen space (i.e., number of pixels) that an information item currently consumes (Algorithm 3). The clutter component lowers the visual score for information items that consume a large amount of screen space in their current representation (e.g., full details consume more space than residue). This component verifies that if the GVA algorithm determined that an item should use a large amount of screen space, then the item will have the visual score to support that result.

Algorithm 3: The calculation of Clutter.

For information item, i,

$S_i = ScreenSpace(x_i, y_i, e_i, s_{i,})$

Where the function $ScreenSpace(x_i, y_i, e_i, s_{i,})$ returns the number of screen units used by i, a positive, possible zero value and $S_{total} \geq S_i$.

$S_{total} = ScreenSpace(x_v, y_v, e_v, s_v)$

Where the function $ScreenSpace(x_v, y_v, e_v, s_v)$ returns the total number of screen units available, a positive nonzero value and $S_{total} \geq S_{empty}$.

$S_{empty} = EmptyScreenSpace(x_v, y_v, e_v, s_v)$

Where the function $EmptyScreenSpace(x_v, y_v, e_v, s_v)$ returns the number of unused screen units, a positive possible zero value.

$[Clutter_i] = \left(1 - \frac{S_{empty} - S_i}{S_{total}}\right)$ with $S_{total} \geq S_{empty}, S_i \geq 0$

The Historically Relevant Component

The *historically relevant* component represents a continuity factor that extends an information item's importance from the recent past to the present. The historically relevant component prevents information items from toggling quickly between being very relevant one moment to not being relevant the next moment, which may cause the item to disappear from the user's view. Instead, the historically relevant component gradually reduces the importance of an information item with time, which forces the visual representation to shift from a higher detail level to a lower level detail gracefully (see Algorithm 4).

The concept of information items disappearing slowly while providing clear evidence of their visual decay is called *information fading*. This concept is important to include in the GVA algorithm, as it is known that removing items from a visualization quickly without the user's knowledge leads to poor system understanding (Wickens et al., 2003).

Algorithm 4: The calculation of Historically Relevant.

For information item, i,

$$HR_i = \sum_{t=t_{now}}^{t_{past}} \text{Visible}(\text{v}_\text{i}, \text{t})$$

Where

The function $\text{Visible}(\text{v}_\text{i}, \text{t})$ returns a value from 0 to 1 depending on how much detailed is displayed at time t (e.g., full detail returns 1, not visible returns 0).

t_{past} is some time in the past.

t_{now} is the current time.

$T_i = t_{now} - t_{past}$, T_i is a positive nonzero number because $t_{now} > t_{past}$.

$[Historically\ Relevant_i] = \frac{HR_i}{T_i}$.

The Currently Relevant Component

The *currently relevant* component is composed of two subcomponents: relevancy and expiration. *Relevancy* ensures that the information item is relevant, while *expiration* ensures that the information item is current. Relevancy is a positive term indicating how useful this information item is to the current situation. Expiration is a negative term that ensures an information item will disappear slowly, if that item has been removed from the system.

The relevancy subcomponent is based on measuring the answer to the question: "Has this information item been interacted with lately and, if so, how important was that interaction?" The interaction importance is a continuous value between zero and one. The interaction can either be direct (e.g., clicking, hovering) or indirect (e.g., related information items). Our implementation used mouse clicking, mouse hovering, and related information item interaction. Clicking and hovering received an interaction value of one. The related information item interaction was calculated based on the item's meaning class; that is, if another item of the same class received direct interaction, then this item was rewarded with an interaction value of 0.4. This indirect interaction type allows the visualization to highlight information items that may be related to the currently interacted item, thereby facilitating certain types of decision making. For example, when a user interacts directly with an eye-witness report information item to determine if a robot (i.e., unmanned vehicle or UV) search task is required, other eye-witness reports, because of the indirect interaction reward, have their relevancy subcomponent values increased. This causes the other eye-witness reports to become more salient and improves the participant's overall understanding of the eye-witness reports' distribution or geographical pattern, which may support determining the UV search task location or the participant's current goal.

Using these two subcomponents, relevancy and expiration, the clutter component can be expressed algorithmically by Algorithm 5.

Algorithm 5: The calculation of Currently Relevant.

For information item, i,

Let $\mathrm{A_i}$ be the set of interaction pairs, $\{\mathrm{t_a}, \mathrm{I_a}\}$, for i such that $\mathrm{t}_{now} \geq \mathrm{t_a} \geq \mathrm{t}_{now} - \mathrm{t}_{too\ long\ ago}$

Where:

$\mathrm{t_a}$ is the time of the interaction

$\mathrm{I_a}$ is the type of interaction.

t_{now} is the current time.

$\mathrm{t}_{too\ long\ ago}$ is a constant time in the past that is considered too long ago from t_{now} to matter.

$$\mathrm{R}_i = \sum_{\mathrm{a}}^{\mathrm{A_i}} \mathrm{ValueOfInteraction}(\mathrm{I_a}) * \mathrm{SomeDecayFunction}(\mathrm{t}_{now} - \mathrm{t_a})$$

Where:

$\mathrm{ValueOfInteraction}(\mathrm{I_a})$ is a function that returns a value from 0 to 1 denoting the importance of this type of interaction (e.g., editing item returns 1, mouse hover returns 0.5, etc).

$\mathrm{SomeDecayFunction}(\mathrm{t}_{now} - \mathrm{t_a})$ is a function that returns a value from 1 (when $\mathrm{t}_{now} - \mathrm{t_a} \leq 0$) to 0 (when $\mathrm{t}_{now} - \mathrm{t_a} \geq \mathrm{t}_{too\ long\ ago}$).

Let $\mathrm{A_{all}}$ be the set of interaction pairs, $\{\mathrm{t_a}, \mathrm{I_a}\}$, for all information items such that $\mathrm{t}_{now} \geq \mathrm{t_a} \geq \mathrm{t}_{now} - \mathrm{t}_{too\ long\ ago}$.

Compute $\mathrm{R}_{all} = \sum_a^{\mathrm{A_{all}}} \mathrm{ValueOfInteraction}(\mathrm{I_a}) * \mathrm{SomeDecayFunction}(\mathrm{t}_{now} - \mathrm{t_a})$.

Then $[Relavency_i] = \begin{cases} \frac{R_i}{R_{all}} & if\ R_{all} > 0 \\ 0 & if\ R_{all} = 0 \end{cases}$.

If i has a removal time, $\mathrm{t_{removal}}$

$E_i = \mathrm{SomeDecayFunction}(\mathrm{t} - \mathrm{t_{removal}})$.

Else

$E_i = 0$

Then $[Expiration_i] = E_i$.

Therefore,

$$[Currently\ Relevant_i] = \mathrm{k_9}[Relavency_i] + \mathrm{k_{10}}[Expiration_i] = \mathrm{k_9}\begin{cases} \frac{R_i}{R_{all}} & if\ R_{all} > 0 \\ 0 & if\ R_{all} = 0 \end{cases} + \mathrm{k_{10}}E_i$$

Where $\mathrm{k_n}, \mathrm{n} = 9{,}10$ are scalar constants used to determine the relative importance of each component.

The Novel Component

The Equation 1 *novel* component is essentially a calculation of an item's uniqueness, where uniqueness represents how different the information item is from all other information items. The *uniqueness* factor can be computed as the result of an algorithm that answers the question: "How different is the meaning of this information item from all other information items?" as provided in Algorithm 6.

Algorithm 6: The calculation of Novel.

For information item, i,
Let C_i be the set of information items, *c*, that are members in the information item, i, class(es).
$U_i = |C_i|$, meaning the number of items in C_i, a nonnegative number.
$N = \text{total \# of information items}$, a positive nonzero number.

$[Novel_i] = \frac{N - U_i}{N}$.

The Emerging Component

The *emerging* component is composed of two subcomponents: youth and emerging relevancy. The *youth* subcomponent represents how long ago an information item was created or entered into the system. The more recent an information item was created, the younger and more emergent it is.

The second subcomponent, *emerging relevancy*, is based on the average visual score of other existing similar (i.e., same information type) information items. The emerging relevancy feature is a component of the emerging term because not all emerging information items are equally important. Displaying an emerging, but unimportant information item may not be useful and may distract from other useful information items. For example, if a visualization is currently displaying all bombs in an effort to determine which bombs to defuse first and then a cow (i.e., something unimportant) and a bomb-defusing robot appear simultaneously. Both the cow and the robot are unique; however, the robot is clearly more relevant than the cow at this moment. Therefore, the bomb is rewarded for its relevancy and displayed more saliently.

The emerging relevancy subcomponent for the novel component in Equation 1 cannot be computed in the same manner as it was computed in the currently relevant component because a new information item has no interaction history. Therefore, the emerging relevancy factor subcomponent for the novel component will be based on whether or not items with similar meaning are visible. For example, if the user is currently interacting with bomb information items then the bomb information items will be very visible when a new bomb item is created and this new bomb item will also be deemed relevant. The relevancy subcomponent is computed as the similarity to visible subcomponent of the clutter component (see Algorithm 3's second component). Thus by using the similarity to visible component as the emerging component's means of computing relevancy, the novel and emerging components in the max function from Equation 1 counteract the clutter's use of similarity to visible in its computation. Therefore, information items that are novel and emerging do not have their visual scores reduced, as there are other items with similar meanings currently being displayed. If similarity to visible was not a factor in the novel and emerging component, information items that are too similar to other items currently being displayed will likely appear as residue or be grouped with similar items, thereby potentially hiding the fact that they are new to the system.

Using the two subcomponents youth and emerging relevancy, the emerging component can be expressed algorithmically, as provided in Algorithm 7.

Algorithm 7: The calculation of Emerging.

For information item, i,

Compute $\mathrm{Y}_i = \mathrm{SomeDecayFunction}(\mathrm{t}_{now} - \mathrm{t}_{\mathrm{created}})$

Where:

$\mathrm{SomeDecayFunction}(\mathrm{t}_{now} - \mathrm{t}_{\mathrm{created}})$ returns a value from 1 (when $\mathrm{t}_{now} - \mathrm{t}_{\mathrm{created}} \leq 0$) to 0 (when $\mathrm{t}_{now} - \mathrm{t}_{\mathrm{created}} \geq \mathrm{t}_{too\ long\ ago}$).

t_{now} is the current time.

$\mathrm{t}_{\mathrm{created}}$ is when the information item was created.

$\mathrm{t}_{too\ long\ ago}$ is a constant time in the past that is considered too long ago to matter.

$$[Youth_i] = \mathrm{Y}_i$$

Let $\mathrm{C_i}$ be the set of information items, *c*, that are members in the information item, i, class(es).

$$U_i = \sum_{c}^{\mathrm{C_i}} \mathrm{Visible}(\mathrm{v_c}, \mathrm{t})$$

Where the function $\mathrm{Visible}(\mathrm{v_c}, \mathrm{t})$ returns a value from 0 to 1 depending on how much detail is displayed at time t (e.g., full detail returns 1, not visible returns 0).

$N_i = |\mathrm{C_i}|$, meaning the number of items in $\mathrm{C_i}$.

$$[Emerging\ Relevancy_i] = [Similarity\ to\ Visible_i] = \begin{cases} \frac{U_i}{N_i} & \text{if } N_i > 0 \\ 0 & \text{if } N_i = 0 \end{cases}.$$

$$[Emerging_i] = \mathrm{k}_{11}[Youth_i] + \mathrm{k}_{12}[Emerging\ Relevancy_i] = \mathrm{k}_{11}\mathrm{Y}_i + \mathrm{k}_{12}\begin{cases} \dfrac{U_i}{N_i} & \text{if } N_i > 0 \\ 0 & \text{if } N_i = 0 \end{cases}$$

Where $\mathrm{k_n}, \mathrm{n} = 11{,}12$ are scalar constants used to determine the relative importance of each component.

Information Item Representation

The last GVA algorithm component represents the information with a shape. The shape is partly determined by the high/low resolution distinction. The high-resolution information may be presented in a manner that preserves as much distribution information as possible. *Distribution information* arises from grouping individual information items together into a single new super information item. The locations of individual information items in the super item become the distribution information of the super item. The distribution information can be encoded using a color component such as saturation, luminosity, or transparency. Color components have been successfully used to represent several levels of a particular value in other contexts (Wickens et al., 2003). The low-resolution information can be represented with an icon, symbol, or marker shape thereby preventing the low-resolution information from detracting from the high-resolution information.

The Halo Concept

One may ask the question, "What happens if an information item has a high visual score and should be displayed, but the item is not geographically within the currently viewable area of the interface?" This case is handled by adding a halo area surrounding the main window view in order to display these information items (see Figure 34) and by adding a new component to Equation 1. The display screen is thereby split into two components: a main view area and a halo area. The halo area has been employed in earlier human robot interaction work (Humphrey, Henk, Sewell, Williams, & Adams, 2007). The halo concept is structurally similar to the Focus plus Context visualizations (Baudisch et al., 2002) in that it is designed to provide context to the main viewing area, which is the focus. The information items in the halo area, unlike the Focus plus Context, do not have their full geographic location expressed. Information items in the halo area are placed according to their relative location from the main view without any indication of distance from the main view, except that they reside beyond that area. The halo area allows the user to maintain awareness of information items outside the main view and provides an indication of how to navigate the visualization to view the items in more detail without using a distorted visual geometry, as is applied with the Focus plus Context visualization. Information items in the main view area still have their full geographic location information displayed, whereas information items in the halo area only have a portion of their geographic location information displayed, (i.e., their relative location to the main view.)

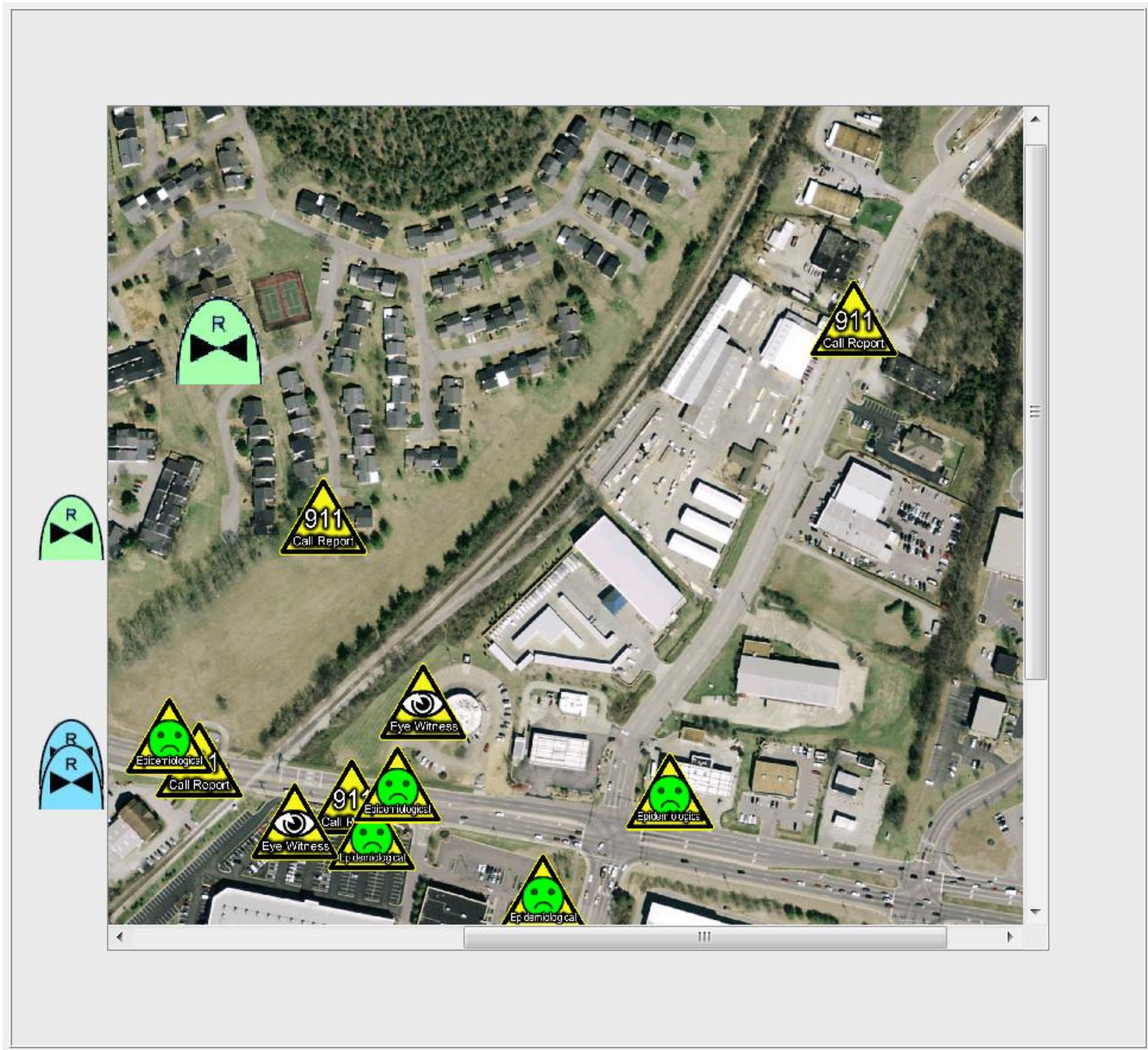


Figure 34: The halo area is the space surrounding the map in the center. In this figure, the halo area has three information items displayed on the left side.

Equation 1 is modified for use with the halo concept by adding an in-view component (see Equation 4). The in-view component only affects items displayed in the halo area and does not affect information items in the main view. This component reduces the visual score of information items as they move farther away from the main view. Without a reduction in visual score based on distance from the main view, all information items not displayed in the main view will be displayed in the halo area, rendering the halo area ineffective. The in-view component, therefore, prevents unnecessary information items from cluttering the halo area while still allowing important information items to be displayed regardless of their distance from the main viewable area. The in-view component can be computed, as depicted in Algorithm 8, as the result of an algorithm that answers the question: “Is the information item in the viewing space and if not, how close is it?”

Equation 4: The calculation of the GVA algorithm’s visual score for use with the Halo concept.

$$v = k_0[In\ View] + k_1[Predetermined\ Importance] - k_2[Clutter] + \max\begin{cases} k_3[\text{Historically Relevant}] + k_4[\text{Currently Relevant}] \\ \quad or\ k_5[\text{Novel}] + k_6[\text{Emerging}] \end{cases}$$

Where:

$k_n, n = 0,1,...$ are scalar constants used to determine the relative importance of each component.

[ ] represents a component which returns a value in the range from -1 to 1.

Algorithm 8: The calculation of In-View.

For information item, i,

If information item’s, i, volume, $(x_i, y_i, e_i, s_{i,})$, is completely contained inside the viewing space, (x_v, y_v, e_v, s_v),

Compute $D_i = 0$

Else

Compute $D_i = \text{SomeDecayFunction}\left(Distance\ \left((x_i, y_i, e_i, s_{i,}), (x_v, y_v, e_v, s_v)\right)\right)$

Where:

SomeDecayFunction( ) is a function that returns a value from 1 (when $D_i = 0$) to 0 (when $D_i \geq D_{too\ far}$) and $D_{too\ far}$ is a distance when an information item is too far away to consider context for the main view.

$Distance\ \left((x_i, y_i, e_i, s_{i,}), (x_v, y_v, e_v, s_v)\right)$ is a function that returns a the geometric distance between the center of these two volumes, a positive nonzero number.

$[In\ View_i] = D_i$

GVA Algorithm Summary

In summary, the GVA algorithm addresses the information abstraction and presentation issues in directable visualizations, such as the CBRNE system. The algorithm facilitates abstraction by employing a more robust understanding of information item importance to compute a visual score. The visualization abstraction provided by the algorithm filters, groups, and displays information items to support decision-making, even when the information types and the decision types are unknown.

Decision Information Abstracted to a Relevant Encapsulation (DIARE)

The purpose of sharing information across User Levels is either to provide support for the user's decision or to provide evidence in support or opposition of another user's decision. Only the information relevant to this purpose needs to be shared: nothing more (e.g., all system information) and nothing less (e.g., shared flags). Many visualization sharing techniques are either inflexible (e.g., shared space and large-scale displays), indirect (e.g., shared flags and shared annotations), do not explicitly deal with time (e.g., shared flags, shared annotations, activity lists) or require translation (e.g., instant messaging, shared flags, and shared annotations). None of these methods share collections of information items directly or explicitly allows users at different User Levels to view the information differently from each other. The Decision Information Abstracted to a Relevant Encapsulation, or DIARE, concept is designed to address these shortcomings.

The DIARE concept is designed to address information sharing for emergency incident related geographic information systems (GIS). The DIARE concept is based on the idea that evidence for a particular decision can be represented as a defined volume in the visualization's information space spanning the six components [*x, y, e, t, s, m*]. This defined volume becomes an object, or DIARE object, and contains information relating to that particular decision (i.e., range of *m*) in terms of a spatial area (i.e., range of *x*, *y*, and *e*), time range (*t*), and detail range (*v*). A DIARE object acts as a super information object that can be shared between and across User Levels and can itself become an element in the visualization. For example, several DIARE objects can be created by the person supervising the UVs during an area survey and later someone else can search an overlapping area for any DIARE objects that deal with unusual items. This later action can cause the visualization to display one or two previously created DIARE objects as information items on the geographical map.

Comparing DIARE with Activity Sessions

The DIARE concept is similar to the activity sessions concept (Tomaszewski & MacEachren, 2006), discussed in Chapter II, but differs in two key ways. An activity session is designed to conceptually represent the same thing as a DIARE object: a logical collection of information entities that illustrate an idea or problem; however, the mechanics are very different. Activity sessions employ shared annotations with time to capture the idea, albeit indirectly, whereas a DIARE object encapsulates the information to be shared and shares the information directly and completely. The DIARE object does not require the translation that an activity session requires (i.e., mapping from an artifact back to the related information items.)

Sharing Across User Levels

A DIARE object allows other users to view the shared information items in any way that the general visualization supports because a DIARE object represents a collection of information items in a volume of space rather than a static image of the information items. This approach implies that different User Levels can view a DIARE object in different manners in order to best support their needs.

For example, if the operator User Level (i.e., the responders who directly supervise the UVs) believes that the information being viewed currently indicates that there may be a hidden secondary hazard device, the operator can capture that collection of information and form a DIARE object. The DIARE object can then be easily shared with the supervisor User Level (i.e., the person who manages operator User Level responders) for notification or guidance. The supervisor can view the information items in the DIARE object in the same manner as the operator or in a different manner (e.g., different detail level) to perhaps support another task that the supervisor is directing. Later this DIARE object can be recalled and subsequently incorporated into another DIARE object; for example, relating the hidden secondary hazard device DIARE object to the task of defusing the device.

Visually, a DIARE object may be displayed as an interactive motion clip accompanied with additional notes regarding the object's purpose or relevant features. The DIARE concept has four visual components and three states: unselected (i.e., no visual DIARE object is highlighted Figure 35a), selected (i.e., a visual DIARE object is highlighted Figure 35b), and creating a new DIARE object (Figure 35c). The unselected state is the default state and displays three of the possible four components (Figure 35a): the incident timeline (i.e., top left time bar), the DIARE timeline (i.e., the bottom left section with the grey background), and visual DIARE objects (i.e., the entities with pictures in the DIARE timeline).

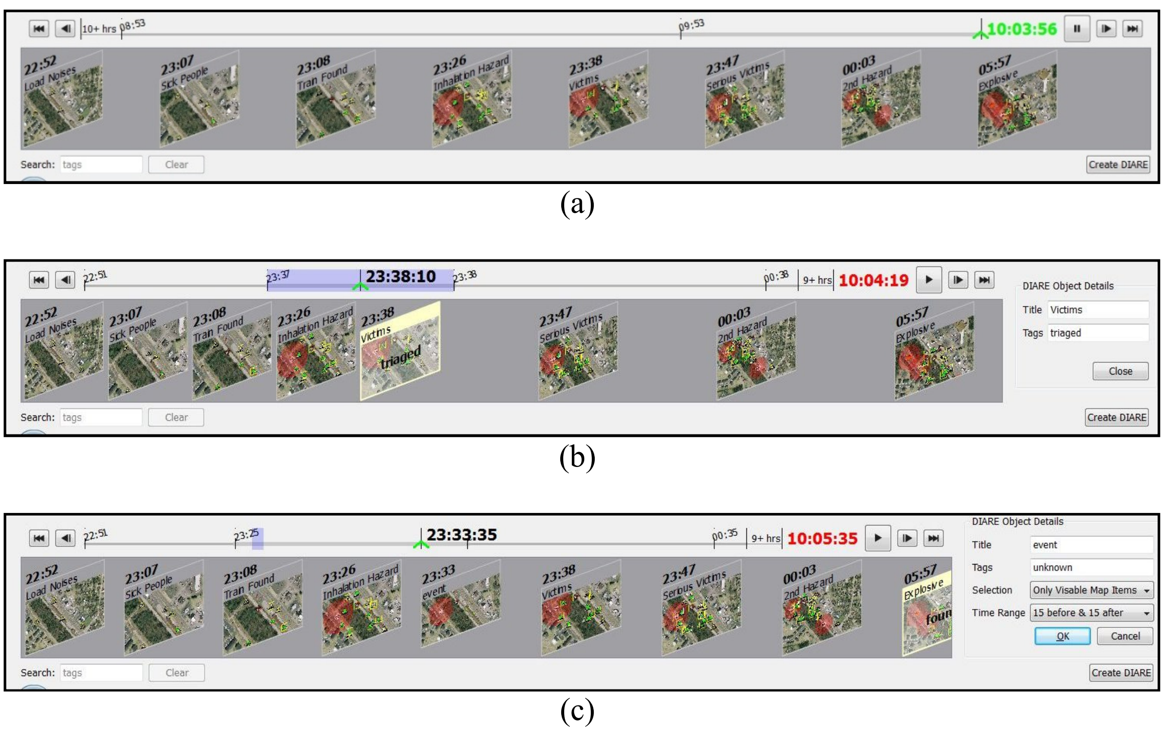


Figure 35: The DIARE concept visual components depicted in its two of its three states: unselected (a), a selected DIARE object (b), and create new DIARE object (c)

The incident timeline is a variable stepwise linear bar; that is, between two time ticks or a time section (i.e., a horizontal bar with a corresponding time), the time scale is linear, but different time sections have different scales. The different scales allow the incident timeline to display all possible times without using a scrolling mechanism. The incident timeline; therefore, is a type of generalized fisheye display (G. W. Furnas, 1986) and is analogous to fisheye calendars or timelines (Bederson, Clamage, Czerwinski, & Robertson, 2004; Dachselt & Weiland, 2006). Additional features of the incident time bar are common movie buttons (e.g., play, skip forward) and two times: the current or *now time* and the current *display time* (i.e., the time of what is currently being displayed on the map). If the system's map is displaying the current time, then the *now time* (i.e., the 10:03:56 time display on the right edge of the DIARE in Figure 35a) is displayed in green and is the only large horizontal time display on the incident timeline. If the system's map is displaying some time point in the past, then the *display time* appears usually centered in the incident timeline and the *now time* changes color to a dark red (e.g., 23:38:10 in Figure 35b).

The DIARE timeline displays the visual DIARE objects in chronological order from oldest on the left to youngest on the right. The DIARE timeline, when no visual DIARE objects are selected, spaces the objects as evenly as possible (Figure 35b) across the timeline. This timeline does not attempt to encode meaning into the amount of space between objects. However, it vertically aligns the closest object, time wise, to the *display time* (Figure 35b). When the DIARE timeline aligns an object, objects on either side of this aligned object are spaced evenly across the timeline. The DIARE timeline will never obscure one visual DIARE object with another (i.e., no overlaps); therefore, it is possible for some objects to be outside (i.e., not visible) the timeline.

A visual DIARE object is the graphical representation of a DIARE object that is displayed on the DIARE timeline. The information contained in the visual DIARE object includes title, start time, tags, and snapshot. The title is the proper name of an object; whereas, the tags are details or related topics. The snapshot is a picture of the map as it was displayed to the user at the start time.

The create DIARE object panel is the fourth DIARE component and is only present during the selected or create new states, and is the right side form presented in Figure 35c. The create DIARE object panel allows users to add information, such as title and tags to new objects and edit existing objects. The user selects the “Create DIARE” button to initiate the creation of a DIARE object, the bottom right corner of Figure 35a. Two additional options are available for creating a DIARE object: item selection and time range. The item selection menu allows users to quickly specify basic selections to be encapsulated in the DIARE object (e.g., all visible items, only large visible items, only items selected by the user). The time range allows users to quickly specify basic time windows relative to the time the DIARE object was created to be represented in the DIARE object (e.g., 15 seconds before and after, 2 minutes after, user specified).

The overall interface goes through a number of changes when a DIARE object is selected. Figure 36 provides an example of the interface showing real-time information (e.g., current time) from the emergency response. In this figure, no DIARE object has been selected (as in Figure 35a). When the user selects a particular DIARE object (as in

Figure 35b) the interface presents a different set of information, as presented in Figure 37. The selected DIARE object becomes highlighted, the now time changes color from green to red, the display time is set to the DIARE objects' start time and appears near the center of the incident timeline in bold black values (e.g., 13:15:53), and the selected DIARE object moves such that it is aligned with the display time in the middle of the scale. In addition to the changes within the DIARE section, the main map view no longer displays the real-time information, but rather transitions (e.g., zoom, recenters, and "winds backwards") to display the relevant information items. The relevant information items represent the information that existed on the map at the time the DIARE object was created. In essence, the DIARE object encapsulates the information from the designated time period. The DIARE object in Figure 37 represents a time period of 60 seconds. Once the interface changes, described above, occur, the system plays the "video" represented in the DIARE object's captured time frame. The user is able to stop or pause the playback and can replay the "video" as many times as necessary. The user can return the main map to the current, real-time display by either clicking on the now time or by clicking the jump to end button (i.e., far right button).

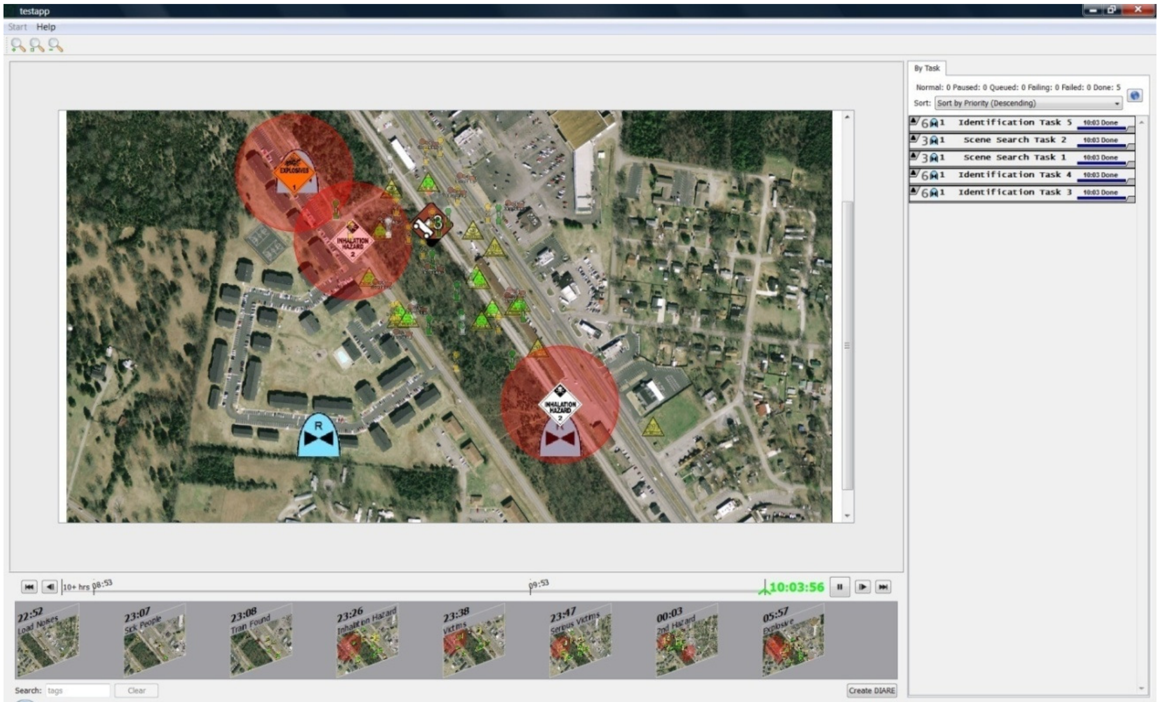


Figure 36: The Interface Program Layout depicting the DIARE section (bottom left), the robot tasks (right edge), and the map with corresponding map items and aerial photograph. The DIARE concept is in its unselected state.

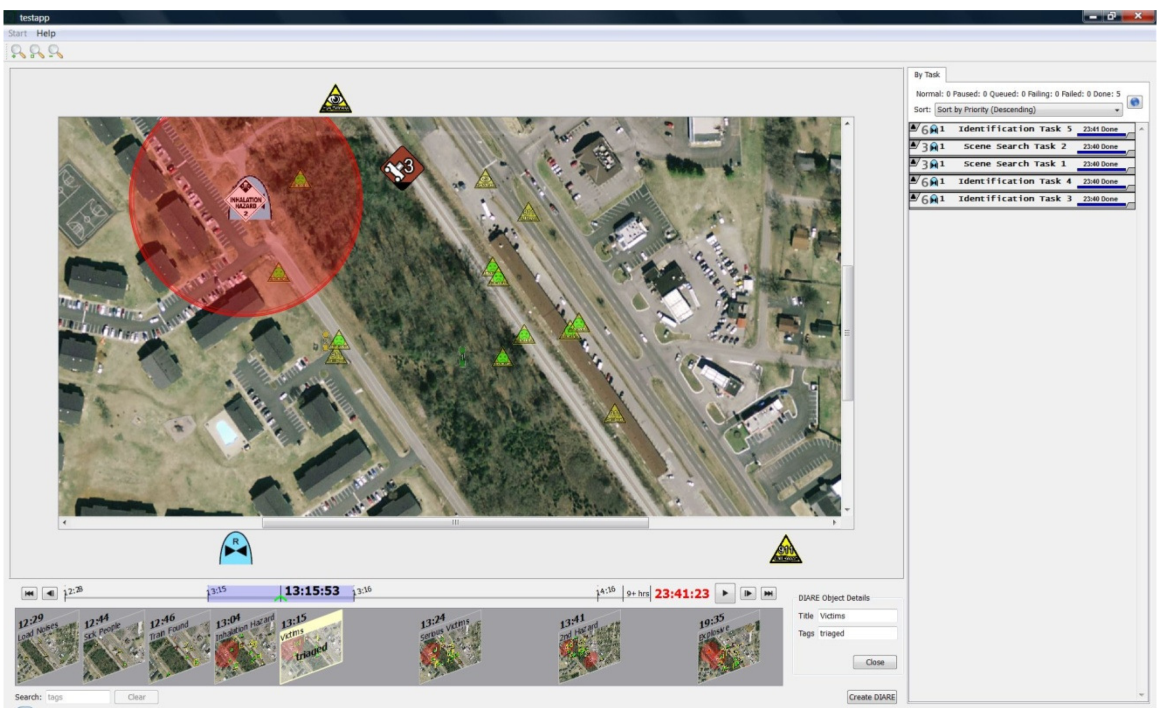


Figure 37: The Interface Program Layout depicting the DIARE concept is in its selected state.

DIARE Summary

The DIARE object is a novel concept in two ways. First, a DIARE object represents a collection of information items in a volume of space rather than a static image of the information items. Secondly, users may view the DIARE object in as many ways as the general visualization supports. Both of these attributes are not present or are severely lacking in other information sharing techniques.

Temporal Navigation

The last problem area is temporal navigation in the CBRNE response system. Navigation through time is often aided with time marks or the highlighting of key frames or time segments (Wickens et al., 2003). A classic example of time marks is the scenes in the scene selection menu on DVDs. Research regarding navigation through time exists (Dachselt & Weiland, 2006) and this author is not proposing a new means of navigating through time, but rather a new manner of creating time marks automatically for information visualization, such as the incident system. The idea is to create time marks automatically based on the outputs of the previous two solutions: the GVA algorithm and the DIARE objects. The time marks may be added when the GVA algorithm highlights novel or emerging information items or when DIARE objects are created. The automatic creation of time marks will facilitate a more effective navigation through time.

Interaction and Independence

The GVA algorithm and the DIARE concept are designed to work together and to work independently. The DIARE concept is designed as a mechanism to share directly an information volume (i.e., DIARE object). The GVA algorithm adds another dimension to the information item's sextuplet [*x, y, e, t, s, m*]: the item's visual score (*v*). Therefore a visualization employing the GVA algorithm has information items with seven dimensions, [*x, y, e, t, s, m, v*], and the DIARE concept then can extend naturally to share all the dimensions in this expanded information space. The user viewing the DIARE's information volume, or DIARE object, can view the information as it was presented at the time the DIARE object was captured (i.e., using the stored visual score data) or how the viewer prefers (i.e., by interactively altering the visual scores). Furthermore, DIARE objects that are represented as information items on the map-based visualization can utilize the GVA algorithm to determine its visual state.

Clearly, the GVA algorithm and DIARE concept can be employed together; however, the two visualizations can also be used independently. The GVA algorithm can be utilized in an interface that does not store history and does not have multiple users. Such an interface has no use for the DIARE concept; however, the GVA algorithm can still provide a benefit to the user and can be used without limitation. Likewise, there may be interfaces that employ extensive domain specific heuristics to determine visualization presentations and, therefore, has no use for the GVA algorithm (i.e., a visualization that displays only weather patterns). In this case, the interface incorporates history and multiple users. Such an interface can still utilize the DIARE concept in order to share information across both users and time. In summary, the GVA algorithm and the DIARE concept can be utilized in the same interface providing good synergy and interaction; however, the two visualizations can also be deployed independently without consequence.

Summary

The proposed robotic technologies for the CBRNE response system will use computer-based visualizations that must address three problem areas: information abstraction and presentation, relaying information to different User Levels, and temporal navigation. This chapter proposed the General Visualization Abstraction (GVA) algorithm to facilitate the information abstraction and presentation, the Decision Information Abstracted to a Relevant Encapsulation (DIARE) object concept to provide information sharing, and using the GVA algorithm and DIARE object results together to assist temporal navigation. Together, these concepts will improve abstraction and presentation, relaying information to different User Levels, and temporal navigation in directable visualization system such as the proposed CBRNE robotic system.

CHAPTER VII

GVA ALGORITHM EVALUATIONS AND RESULTS

The concept motivating the GVA algorithm is that an information item *can* be valued, and, in turn, visualized, based on its relationship with the two information classes: historically and currently relevant information, represented by terms 3 and 4 in Equation 4 (page 162); and novel and emerging information, represented by terms 5 and 6. A *primary objective* for conducting an experiment is to verify that using the GVA algorithm is an improvement for two different Human-Robot Interaction User Levels, or User Levels (see Chapter IV), over the baseline condition of not using the GVA algorithm. The baseline condition represents a standard approach often used to determine the visualization of information items (Cui et al., 2006; Ellis & Dix, 2006; Jul & George W. Furnas, 1998; Cai et al., 2006; Ward, 2002).

Beyond the primary objective, experiments will be conducted to provide additional insight into the effects of the different components of the GVA algorithm. Therefore, the secondary objective is to verify that the complete GVA algorithm is an improvement over using either information class alone (i.e., using only historically and currently relevant information or only novel and emerging information).

General Design of Experiments

The presented evaluations are the first to focus on the GVA algorithm. As such, the focus of the experimental objectives is on verifying assumptions in the theoretical arguments of the GVA algorithm. The objectives are not focused on evaluating the relationship between the resulting interface design and the CBRNE domain (e.g., the interface design's suitability to be used in a real CBRNE response situation).

The environments represented by the system (i.e., the maps), the tasks performed by the participants, and the context were based on a real CBRNE response scenario (see Chapter III). The participant's environment (i.e., the location of the participant and the computer interface) is not representative of a real CBRNE response situation and the participants themselves will possess no domain specific knowledge. A quantitative evaluation of whether or not the interface used in these experiments is suitable, or ecologically valid, for the CBRNE domain is outside the scope of these evaluations.

The proposed CBRNE response system has many different Human-Robot Interaction (HRI) User Levels (User Levels) requiring different information presentations (see Chapter IV). The GVA algorithm implementation was evaluated at the UV Specialist (US) and Operations Chief (OC) User Levels to ascertain its effectiveness (see Figure 23 on page 99 for a review of User Levels). The US User Level represents an individual who commands the unmanned vehicles, or UVs, by providing tasks and goals to be accomplished at an operator/supervisor human-robot interaction role (Scholtz, 2003). The OC User Level represents the Operations Chief who is responsible for directing the response and represents the abstract supervisor human-robot interaction role (see Chapter IV). Mathematically, the interaction role differences represent differences in how information items are grouped by the GVA algorithm. By default, only information items of the same type are considered similar and can be grouped. At more abstract User Levels, items of different, but related types are considered similar and can be grouped. A

Cognitive Information Flow Analysis (CIFA) of the CBRNE domain provided insight as to which items are considered "logically similar" at the more abstract User Levels (see Chapter V).

The GVA algorithm has two sets of evaluation objectives (i.e., primary and secondary). Each set of evaluation objectives lends itself to different statistical designs; therefore, two separate and independent evaluations were conducted. The evaluations are primarily a behavioral evaluation; therefore, the design had to consider and adequately account for the issues of learning and crossover effects (i.e., that one condition will have an effect on another, otherwise independent condition). The remainder of this section presents the two evaluations and discusses learning and crossover effects.

General Evaluation Conditions

The primary and secondary objectives of the evaluations are to compare the GVA algorithm against different conditions. The primary objective has two conditions, while the secondary objective introduced two additional conditions for a total of four conditions. The conditions will henceforth be labeled Non-GVA, NE, HC, and Full-GVA. The Non-GVA was the baseline condition where the GVA algorithm was not used (Algorithm 9). The NE condition employed the full GVA algorithm (Algorithm 1 on page 145), but the visual score equation (Equation 4 on page 162) was modified to only used on the novel and emerging information GVA algorithm component (Equation 5). The HC condition also employed the full GVA algorithm, but the visual score equation was modified to only used on the historically and currently relevant information (Equation 6).

The Full-GVA condition represents the complete GVA algorithm (Algorithm 1 on page 145) and the complete visual score equation (Equation 4 on page 162).

Algorithm 9: The non-GVA condition: Not using the GVA algorithm (Baseline algorithm)

For each time step:
For each information item, i
If i has the mouse hoving over it
Then display the item, i, in full details.
Else
Then display the item, i, in low details.

Equation 5: The NE condition (i.e., without historically and currently relevant) condition version of the GVA algorithm's visual score

$$v = \mathrm{k}_0[In\ View] + \mathrm{k}_1[Predetermined\ Importance] - \mathrm{k}_2[Clutter]$$

$$+ \max\begin{cases} \cancel{\mathrm{k}_3[\text{Historically Relevant}] + \mathrm{k}_4[\text{Currently Relevant}]} \\ \mathrm{k}_5[\text{Novel}] + \mathrm{k}_6[\text{Emerging}] \end{cases}$$

Equation 6: The HC condition (i.e., without novel and emerging) condition version of the GVA algorithm's visual score

$$v = \mathrm{k}_0[In\ View] + \mathrm{k}_1[Predetermined\ Importance] - \mathrm{k}_2[Clutter]$$

$$+ \max\begin{cases} \mathrm{k}_3[\text{Historically Relevant}] + \mathrm{k}_4[\text{Currently Relevant}] \\ \cancel{\mathrm{k}_5[\text{Novel}] + \mathrm{k}_6[\text{Emerging}]} \end{cases}$$

The First Evaluation

The first GVA evaluation focused on the objective of comparing two conditions: the non-GVA and Full-GVA conditions at two different User Levels (see Chapter IV). The two User Levels used in the first evaluation are the UV Specialist (i.e., the human-robot interaction (HRI) operator role) and the Operations Chief (i.e., the HRI abstract supervisor role). Each User Level completed two different tasks for each condition in order to increase the generality of the comparison. Therefore, there were a total of four tasks, two for the UV Specialist (US) and two for the Operations Chief (OC) User Levels. Repeating the same tasks for the two conditions made the task a controlled variable, rather than an independent variable in the first evaluation.

The tasks were required to be independent of each other and in their own environments (e.g., maps) in order to reduce crossover effects. That is, each task must use a different map in order to ensure that the learning effects of one task's environment have minimal impact on the other task. The validity of the comparison between the non-GVA and Full-GVA conditions will be strengthened by testing each condition with the same task-environment combinations (i.e., each task is tested in its own unique environment). Testing each condition with different task-environment combinations ran the risk that the condition comparison would be more influenced by the relative difficulty between the task-environment combinations rather than the different GVA conditions. Thus, there were two possibilities: 1) each participant is evaluated with both conditions (i.e., non-GVA and Full-GVA) and, therefore, must repeat each task-environment combination, which would be a within-subjects design. The second possibility was that 2) each participant completes only one condition and, therefore, only sees each task-environment combination once, or a between-subjects design.

Whether a within- or between-subjects design, the evaluation was a two level design (i.e., non-GVA and Full-GVA conditions). Therefore, with a minimum power of 0.80, a type I error of 0.05, and an effect size of 1.0, a within-subjects design required 16 participants (minimum correlation 0.3) and a between-subjects design required 34 participants. However, given that a within-subjects design would result in some crossover effects due to repeating task-environment combinations, the observed effect size may be smaller. Lowering the effect size to 0.75, the within-subjects design required 28 participants rather than 16 participants. Since the difference between the number of participants was small (28 verses 34), the between-subjects design was preferred in order to eliminate possible crossover effects. Therefore, a two level experimental design with 34 participants was employed. The participant pool was divided in half for the two levels, represented by the tables below. Table 2 and Table 3 depict the design of the experiment by first listing the section (e.g., US User Level), the round (e.g., Trial 1), and the case and task-environment in the ordering it may have occurred for a particular participant. The task-environment combination ordering, however, was counterbalanced in each experiment.

Table 2: Design of Experiment for Participant Pool A

Experiment	Round	Task
1: US User Level	Training	non-GVA, Task T & Env T
	Trial 1	non-GVA, Task α & Env 1
	Trial 2	non-GVA, Task β & Env 2
2: OC User Level	Training	non-GVA, Task T2 & Env T2
	Trial 1	non-GVA, Task γ & Env 3
	Trial 2	non-GVA, Task δ & Env 4

Table 3: Design of Experiment for Participant Pool B

Experiment	Round	Task
1: US User Level	Training	Full-GVA, Task T & Env T
	Trial 1	Full-GVA, Task α & Env 1
	Trial 2	Full-GVA, Task β & Env 2
2: OC User Level	Training	Full-GVA, Task T2 & Env T2
	Trial 1	Full-GVA, Task γ & Env 3
	Trial 2	Full-GVA, Task δ & Env 4

The Second Evaluation

The second evaluation compared four conditions: non-GVA, NE, HC, and Full-GVA conditions. The second evaluation did not incorporate the Operations Chief User Level because, at that User Level, the grouping effects obfuscate the effects of the individual GVA components (i.e., historically and currently relevant vs. novel and emerging). At this higher User Level, the visualization becomes a collection of domain specific grouping methods that is relatively invariant to small changes in visual scores. It becomes experimentally infeasible, therefore, to separate the effects of the GVA algorithm components from the effects of the domain specific grouping techniques. Therefore, the GVA algorithm components were evaluated at the lower UV Specialist User Level only.

The four conditions were evaluated by performing two different tasks in order to increase the generality of the comparison between conditions. Each task occurred in its own environment in order to ensure each task was independent of the other and to reduce crossover effects. Each condition was tested with the same task-environment combinations in order to increase the validity of the comparison between the non-GVA, NE, HC, and Full-GVA conditions.

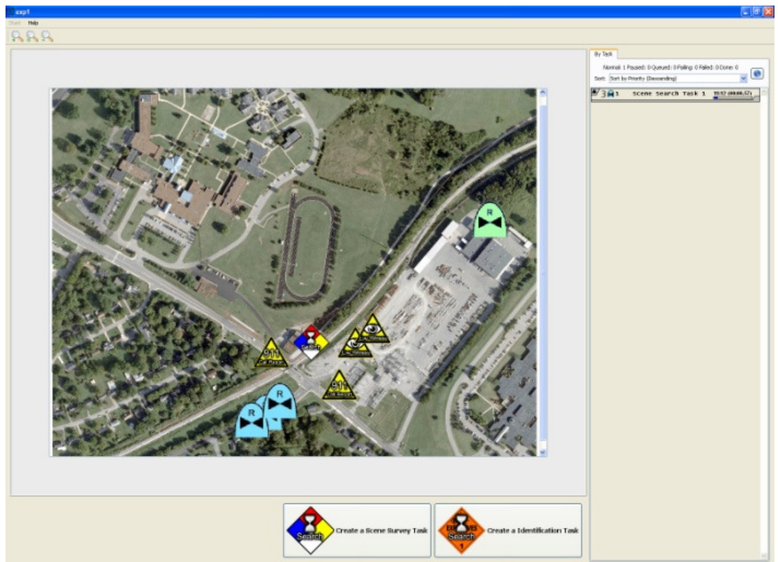
The experiment was a four-level design and could have been conducted as either a within- or between-subjects design. With a minimum power of 0.80, a type I error of 0.05, and an effect size of 1.0, a within-subjects design required 20 participants (minimum correlation 0.3) and a between-subjects design required 92 participants. The within-subjects design would have some crossover effects due to repeating task-environment combinations; therefore, the effect size may have been smaller. Lowering the effect size to 0.75, the within-subjects design required 32 participants. The crossover effects, although present in the within-subjects design, were likely to be small; therefore, a within-subjects design was employed. Fortunately, since both the first and second evaluations were comparing the non-GVA and the Full-GVA conditions, the results of the between-subjects design evaluation will act as verification of the results of the within-subjects design evaluation. Therefore, the following experimental design was employed (see Table 4). Table 4 depicts the rounds, task-environments, and conditions as one participant may have experienced the experiment. The task-environment combination and the case ordering were counterbalanced using a Latin square design.

Table 4: Design of Second Experiment, one possible case task ordering.

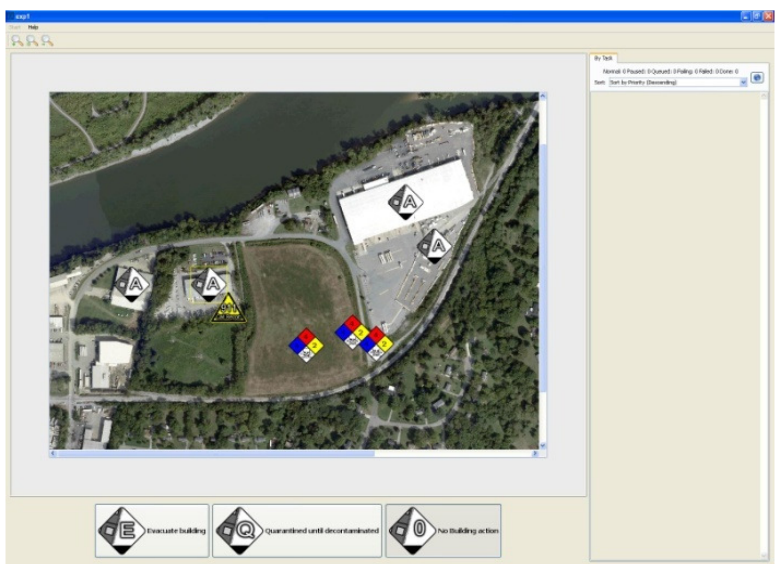
Round	First Task	Second Task	Third Task	Four Task
1	non-GVA, Task α & Env 1	NE, Task β & Env 2	HC, Task α & Env 1	Full-GVA, Task β & Env 2
2	NE, Task α & Env 1	non-GVA, Task β & Env 2	Full-GVA, Task α & Env 1	HC, Task β & Env 2

General Evaluation Apparatus

The developed user interface and response simulator (i.e., interface program) was employed for both experiments. The interface program maintained the same structural layout for both experiments and was comprised of three sections, as seen for each User Level in Figure 38: the left map display section, the bottom task selection section, and the right robot task information display. The tasks displayed in the task selection section were based on the User Level. The participants learned to interact with the different interface components during the system overview and training trial. They were told that any information item (i.e., map icon) was displayable in detail mode (Figure 33a on page 144) by hovering the mouse over an information item or by clicking on an information item.



(a) US User Level

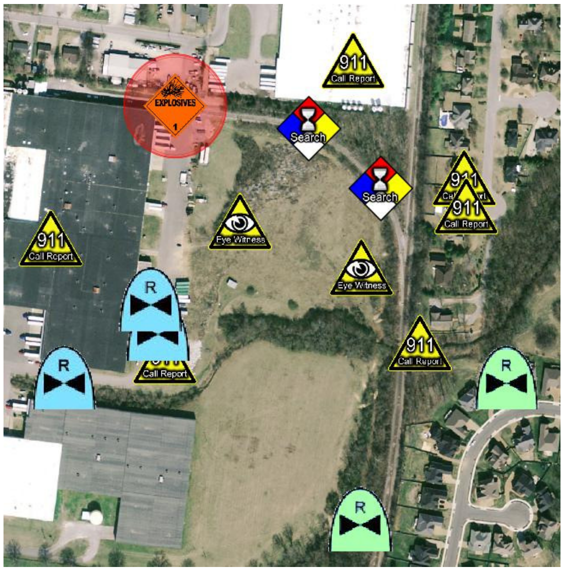


(b) OC User Level

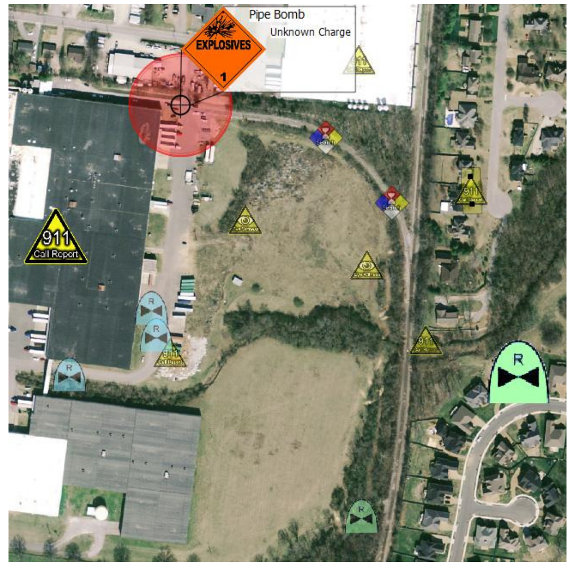
Figure 38: The Interface Program Layout for the US User Level (a) and the OC User Level (b).

A limited number of information item types representing hazards (e.g., explosive), hazard or sensor readings, eye witness reports, vehicles, etc. were displayed on the map. The information item designs were based on existing graphical standards (DOD, 2008; DOT, 2008). All information items were constructed with three visual states (i.e., details, normal, and residue) that shared common elements (e.g., text box and bulls-eye in detail mode) with approximately the same visual size (Figure 33 on page 144).

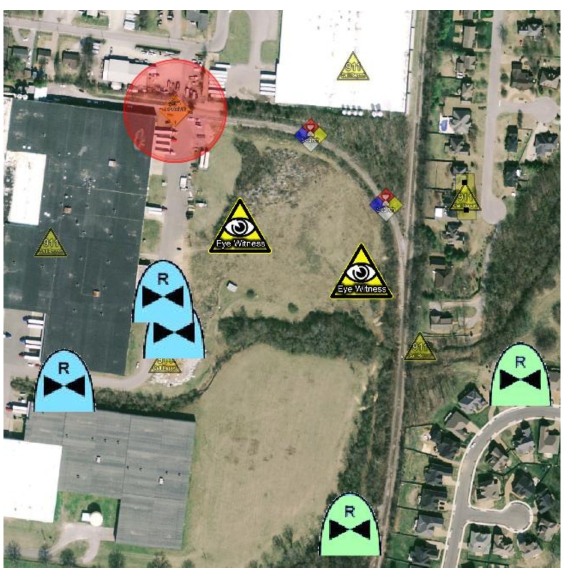
The GVA algorithm is designed to perform well whether or not information items have a predetermined importance. Therefore, for this evaluation, in order to test this feature, all information item types, except UVs and robot task icons, had no predetermined importance value. The UV and robot task icons had a predetermined importance because they were "known" at design time and were important. These two information items were only present at the US User Level and were important because they represented the elements being managed by the operator (e.g., the managed robots (UV icons) and the assigned tasks the robots were to perform (robot task icons)). Their predetermined importance value was 0.4, or 40%. A few information items were visible at the start of each task and information items were added throughout the task. There were between ten and 120 information items displayed on the map, depending on the elapsed time, the User Level, and the participant's interactions. Figure 39 depicts the four evaluation conditions for the same task-environment at the same time, resulting from the same participant action sequence for the US User Level. The first evaluation conditions are represented by images a and d in Figure 39, while all four conditions in Figure 39 were employed in the second evaluation. The information items are at different sizes due to their visual scores, except for the non-GVA condition, which does not use visual scores and all information items are displayed at the same size.



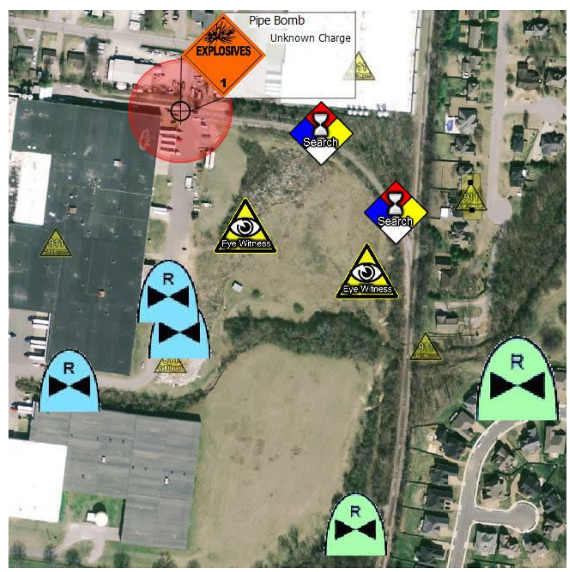
(a) non-GVA condition



(b) NE condition



(c) HC condition



(d) GVA condition

Figure 39: The same task-environment at approximately the same time with the same sequence of interactions depicting the difference between the non-GVA (a), the NE (b), the HC (c), and the Full-GVA (d) conditions.

First Evaluation: Between-Subjects Design

Method

The first evaluation focused on the full GVA and non-GVA conditions at the UV Specialist (US) and Operations Chief (OC) User Levels to ascertain its effectiveness. The US User Level represents an individual who commands the UVs by providing tasks and goals to be accomplished an operator/supervisor human-robot interaction role (Scholtz, 2003). The OC User Level represents the Operations Chief who is responsible for directing the response and represents the abstract supervisor human-robot interaction role (see Chapter IV). The User Levels were evaluated in different experiments with different tasks and environments; yet, the two experiments shared the same apparatus, design of experiment, and participants.

Each experiment employed a between-subjects design and tested two conditions: the user interface employing the GVA algorithm (i.e., the Full-GVA condition) and the user interface not employing the GVA algorithm (i.e., the non-GVA condition), across one training trial and two evaluation trials. Both the training and the evaluation trials lasted approximately four minutes each. Each participant received a system overview, performed one training trial and two evaluation trials for the US User Level (i.e., Experiment 1), followed by the same sequence for the OC User Level (i.e., Experiment 2). The User Level order was consistent with the US User Level assisting in preparing the participant for the OC User Level. Potential bias due to the User Level order was mitigated by not statistically comparing the two User Levels.

Participants

Thirty-four participants completed the evaluation and were compensated $25 USD. The evaluation lasted approximately one hour and fifteen minutes. All participants were at least 18 years of age. Participants were screened for four requirements: at least a high school education, computer competency, no experience with the experimental maps, and no prior exposure to the interface. All participants had normal or corrected-to-normal vision including not being color-blind and were not required to have domain specific knowledge (i.e., CBRNE incident response knowledge). The participants were uniformly divided into two groups, one for each visual condition (i.e., the Full-GVA condition and the non-GVA condition). The task presentation order within each User Level was counterbalanced.

Hypothesis

The experimental **hypothesis** was that the GVA algorithm (i.e., Full-GVA condition) will be quantitatively preferred, require lower workload, improve situational awareness, and allow the participants to perform tasks at the same speed or faster than not using the GVA (i.e., non-GVA).

Procedure

Each participant completed a consent form and background/screening questionnaire. The participants were given an oral explanation regarding the interface layout, interaction with the interface, each type of information icon they would encounter, and the structure and nature of the tasks they were to perform. The participants completed a training trial and two experimental trials for each User Level. The simpler training tasks will allow more time for the participant to explore, interact, and understand each visualization condition (Gonzalez, 2004, 2005). The training tasks were intended to reduce the learning effects between experimental trials 1 and 2 (Wickens et al., 2003). Furthermore, as part of the system overview, the participants were informed of the meaning of each information item (i.e., icon). After each experimental trial, participants completed questionnaires assessing situational awareness, workload, and preferences.

Six unique environments were developed, one for each component (i.e., training and two trials) in each experiment. All trials were based on a realistic CBRNE scenario involving a train derailment precipitated incident (see Chapter III). The trials were independent of each other and used a unique map in order to minimize cross trial learning effects.

Data collection and Metrics

The independent variable is the visual condition (i.e., non-GVA verses GVA) for both experiments. The evaluation's dependent variables include a number of objective and subjective measures. Subjective SA was measured using the 10-Dimensional Situational Awareness Rating Technique (10D SART) (Taylor, 1989; Endsley, 1995b; Endsley & Garland, 2000). Subjective workload was measured using the NASA-Task Load Index (NASA-TLX) (Hart & Staveland, 1988), and the Multiple Resource

Questionnaire (MRQ) (Boles, Bursk, Phillips, & Perdelwitz, 2007). An after trial questionnaire ascertained participants' thoughts regarding each visual condition's utility.

Experiments

This evaluation incorporated two experiments, one for the US user level and one for the OC user level. The general method, including apparatus, design of experiments, and participants, described in the previous section were used for both experiments. The experiment specific method aspects are described within the sections for each experiment. This section presents the experiment for the US user level, including experimental results and discussion, followed by the OC user level experiment specifics, results and discussion. A general discussion is then presented to address across User Level findings.

Experiment 1: UV Interaction Level

Evaluation Trial Tasks

Experiment 1 focused on the US User Level that allows the user to provide tasks and goals to UVs. The trials incorporated four primary tasks. The first task assigned several scene survey tasks based on existing and newly added information items and was motivated by a short narrative. The second task required reacting to newly appearing explosive hazards by assigning a UV investigation task to the vicinity of the hazard. Each trial contained two explosives that appeared at different times. This task required situational awareness levels 1 and 2 (i.e., detection and comprehension) and vigilance. The third task required stopping neutral UVs if their current trajectory would send them into the same area as the participant's UVs. Each trial contained two neutral UVs that appeared and required stopping at different times. This task required situational awareness levels 1, 2, and 3 (i.e., projection), since projection of the neutral UV's path was required in order to determine when to stop its motion. The last task required answering a question relating to a single information item towards the task completion. The participants were told that they would receive such a question, which was intended to objectively measure situational awareness and increase participant engagement.

Objective Metrics

This experiment incorporated eight objective measures. The Number of Hovers measured the number of mouse hover events. Percentage Hovering represented the percentage of time spent hovering over an information item, where hovering is defined as the mouse cursor being positioned over an information item. The Stopped Neutral Time measured the time at which the neutral UV was stopped relative to the last acceptable stop time (i.e., a value of zero, which was calculated geometrically). Negative Stopped Neutral times indicated that the participant stopped the neutral UV late (i.e., after it entered their area), whereas positive times indicated that the participant stopped the neutral UV early (i.e., before the last acceptable time). The Stopped Neutral in Window measure viewed the time stopped neutral times in terms of an acceptable forty-second window (i.e., from the zero point to positive 40). All times inside this window are considered perfect, or a value of zero, and times outside this window are positive, whether early or late. The Bomb Reaction Time represented the reaction time between when a bomb first appeared and when a bomb identification task was created. The Number of Bomb Misses referred to the number of bomb information items for which no identification task was assigned. The Number of Missed Neutral referred to the number of neutral UVs that were not stopped. Finally, the In Task Question objective measure recorded the time to respond to the verbal SA question.

Results

All statistical analyses were two sample comparisons where the alternative hypothesis is that the Full-GVA condition is better than the non-GVA condition's values; therefore, the null hypothesis is that the Full-GVA condition is the same or worse than the non-GVA condition values (one-tailed). All statistical comparisons were Welch's *t* test for two independent unequal sample sizes with possible unequal variance (Welch, 1947). Cohen's d (ES(d)) (1988) and Hedges' g (ES(g)) (1981) effect size measures were computed.

The Number of Hovers, Percentage Hovering, Stopped Neutral Time, Stopped Neutral in Window, and Bomb Reaction Time objective measures for the US User Level were statistically significant, indicating that the Full-GVA condition performed better than the non-GVA condition (Table 5). The Missed Bombs and Missed Stopping a Neutral UV metrics were not significant and infrequent. The In Task Question results were inconclusive.

Table 5: The performance measurements for UV interaction level.

Measurement	Non-GVA M ±CI	Non-GVA Median	GVA M ±CI	GVA Median	Comparisons df	t	p	ES(g)	ES(d)
Number of Hovers[1]	40.41 ±5.00	38.00	32.74 ±3.68	32.50	66	2.68	**<0.01**	0.34	0.59
Percentage Hovering[1]	0.37 ±0.04	0.37	0.31 ±0.04	0.31	66	2.26	**0.03**	0.23	0.48
Stopped Neutral Time[2,3]	-7.43 ±6.95	-8.00	10.14 ±7.30	3.50	131	3.62	**<0.001**	0.35	0.59
Stopped Neutral in Window[1,3]	15.69 ±4.59	11.00	10.18 ±3.23	3.50	131	2.22	**0.03**	0.11	0.33
Bomb Reaction Time[1,3]	18.37 ±4.46	15.67	13.65 ±1.85	9.56	130	2.20	**0.03**	0.11	0.33
Missed Bombs[1]	0.01 ±0.03	0.00	0.04 ±0.05	0.00	134	0.20	0.84	0.03	0.17
Missed Stopping a Neutral UV[1]	0.01 ±0.03	0.00	0.04 ±0.05	0.00	134	0.20	0.84	0.03	0.17
In Task Question Response Speed[1]	0.97 ±0.05	1.00	1.03 ±0.14	1.00	66	0.56	0.58	0.04	0.19
In Task Question Accuracy[3]	1.31 ±0.15	1.00	1.22 ±0.21	1.00	66	0.69	0.49	0.02	0.16

[1]Lower numbers are better; [2]Postive numbers are better, with negative numbers indicating late performance and positive numbers indicating early performance; [3]Time is in seconds

Two objective measurements were particularly significant: Number of Hovers and Stopped Neutral Time (Table 5). On average, GVA participants had 20% fewer hover events and spent 16% less time hovering than those in the non-GVA condition. The Stopped Neutral Time reveals that participants in the non-GVA condition stopped the neutral UVs 7.43 ±6.95 seconds late; whereas, the participants in the Full-GVA condition responded 10.14 ±7.30 seconds earlier then the last acceptable time. Thus, the Full-GVA condition was 17.57 seconds faster.

The weighted NASA-TLX overall workload was 46.86 ±6.75 for the non-GVA condition, while the Full-GVA condition was 40.88 ±5.53, a 13% reduction (Table 6). Although this result is not significant, the non-GVA condition median was higher than the average by more than 8%, indicating that some participants found the workload to be much lower in the non-GVA condition than most other participants, which is a possible artifact of using NASA-TLX for a between-subjects experiment.

Table 6: The NASA-TLX workload analysis results for the UV Level Interface.

Measurement	Non-GVA		GVA		Comparisons			
	M ±CI	Median	M ±CI	Median	t(66)	p	ES(g)	ES(d)
Mental Demand[1]	52.94 ±9.20	62.50	51.47 ±7.83	52.50	0.84	0.41	0.00	0.06
Physical Demand[1]	22.35 ±6.07	15.00	21.47 ±4.78	17.50	0.83	0.41	0.00	0.17
Temporal Demand[1]	52.50 ±8.29	55.00	48.38 ±8.16	47.50	1.17	0.25	0.04	0.21
Performance[1]	36.76 ±8.07	15.00	26.76 ±4.61	20.00	2.40	**0.02**	0.26	0.51
Effort[1]	46.62 ±8.58	50.00	41.76 ±7.10	37.50	1.30	0.20	0.04	0.21
Frustration[1]	36.91 ±7.30	35.00	26.91 ±6.46	22.50	2.31	**0.02**	0.24	0.49
Total Workload[1]	46.86 ±6.75	51.33	40.88 ±5.53	39.83	1.71	0.09	0.11	0.33

[1]Percentages from 0 (low) to 100 (high), with lower being better

Only two of the individual NASA-TLX factors were statistically significant. The performance factor, (i.e., workload due to performing well) was, on average, 27% less for the Full-GVA condition (26.76 ±4.61). The non-GVA condition performance factor value was 36.76 ±8.07, which is a significant difference (p = <0.02, t(66) = 2.40, ES(g) = 0.26, ES(d) = 0.51). The frustration factor for the GVA versus the non-GVA condition, on average, was 27% less. The Full-GVA condition performance factor value was 26.91 ±6.46 versus the non-GVA condition value of 36.91 ±7.30, which is a significant difference (p = <0.02, t(66) = 2.31, ES(g) = 0.24, ES(d) = 0.49). The MRQ (Boles et al., 2007) also captured perceived workload; however, the results were inconclusive with minimal effective sizes (i.e., on average less than 0.1). The MRQ results are provided in Table 7.

Table 7: The MRQ results for the UV interaction level.

Measurement	Non-GVA M ±CI	GVA M ±CI	Comparisons t(66)	p	ES(g)	ES(d)
Auditory Emotional	0.26 ±0.27	0.21 ±0.18	0.92	0.36	0.01	0.09
Auditory Linguistic	0.18 ±0.17	0.18 ±0.19	0.68	0.50	0.00	0.00
Facial Figural	0.18 ±0.17	0.18 ±0.19	0.68	0.50	0.00	0.00
Facial Motive	0.15 ±0.15	0.24 ±0.22	0.33	0.74	0.03	0.16
Manual	1.74 ±0.32	1.79 ±0.37	0.54	0.59	0.00	0.06
Short Term Memory	2.59 ±0.35	2.68 ±0.27	0.46	0.65	0.01	0.09
Spatial Attentive	3.03 ±0.35	3.00 ±0.29	0.76	0.45	0.00	0.03
Spatial Categorical	2.59 ±0.30	2.32 ±0.34	1.54	0.13	0.08	0.28
Spatial Concentrative	2.59 ±0.33	2.24 ±030	1.89	0.06	0.14	0.38
Spatial Emergent	2.59 ±0.39	2.09 ±0.39	1.78	0.08	0.18	0.43
Spatial Positional	2.68 ±0.30	2.41 ±0.31	1.60	0.12	0.08	0.29
Spatial Quantitative	1.79 ±0.37	1.38 ±0.40	1.84	0.07	0.13	0.36
Tactile Figural	0.26 ±0.15	0.29 ±0.27	0.57	0.57	0.00	0.05
Visual Lexical	2.26 ±0.34	2.09 ±0.37	1.16	0.25	0.03	0.17
Visual Phonetic	0.79 ±0.32	0.65 ±0.33	1.12	0.27	0.02	0.15
Visual Temporal	1.85 ±0.41	1.65 ±0.42	1.17	0.25	0.03	0.17
Vocal	0.12 ±0.11	0.06 ±0.08	1.29	0.20	0.04	0.21

[1]Scores can range from 0 to 4. Higher indicates more workload.

The 10D SART's composite score measured participants' perceived SA (Table 8). The overall SA for the Full-GVA condition (17.56 ±1.42) was 8% greater than for the non-GVA condition (16.21 ±1.66); however, the difference is not significant. The 10D SART subcomponent results are presented in Table 8; however, none of the subcomponent results were significant, indicating that there was not a significant improvement in SA for the Full-GVA condition.

Table 8: The 10D SART analysis results for the UV interaction level.

Measurement	Non-GVA		GVA		Comparisons			
	M ±CI	Median	M ±CI	Median	t(66)	p	ES(g)	ES(d)
Instability[1,3]	3.91 ±0.56	4.00	3.88 ±0.38	4.00	0.73	0.47	0.00	0.02
Variability[1,3]	3.97 ±0.52	4.00	4.09 ±0.49	4.00	0.49	0.63	0.01	0.08
Complexity[1,3]	3.88 ±0.47	4.00	3.59 ±0.52	4.00	1.27	0.21	0.04	0.20
Readiness[1,4]	4.38 ±0.40	4.50	4.50 ±0.48	5.00	0.93	0.36	0.01	0.09
Mental Capacity[1,4]	3.68 ±0.42	4.00	3.74 ±0.42	4.00	0.81	0.43	0.00	0.05
Concentration[1,4]	4.35 ±0.37	4.00	4.59 ±0.37	5.00	1.32	0.19	0.04	0.21
Focus[1,4]	3.91 ±0.33	4.00	4.06 ±0.47	4.00	1.03	0.31	0.01	0.12
Info Quantity[1,4]	4.00 ±0.48	4.00	4.32 ±0.38	4.00	1.46	0.15	0.06	0.25
Info Quality[1,4]	4.29 ±0.38	4.00	4.41 ±0.38	4.00	0.97	0.34	0.01	0.10
Familiarity[1,4]	3.35 ±0.44	3.00	3.50 ±0.51	4.00	0.97	0.34	0.01	0.10
Overall SA[2,4]	16.21 ±1.66	15.50	17.56 ±1.42	18.00	1.60	0.12	0.09	0.29

[1]Scores can range from 0 to 6. [2]Scores can range from -18 to42 . [3]Lower is better. [4]Higher is better.

The participants completed a post-task questionnaire assessing the ease of finding existing items, responding to neutral UVs, responding to emerging items, understanding the situation, performing the subtasks well, and using the visualization overall (Table 9). Only the ease of responding to neutral UVs and to emerging items provided significant results and, on average, were found to be 14% and 19% easier, respectively, in the Full-GVA condition. The subjective question, the ease of finding existing items, is the only measurement that found, on average, the non-GVA condition to be perceived as easier than the Full-GVA condition (4.41 versus 4.09); however, this difference was not significant.

Table 9: After Task Questionnaire for the UV interaction level.

Ease of …	Non-GVA		GVA		Comparisons			
	M ±CI	**Median**	**M ±CI**	**Median**	**t(66)**	**p**	**ES(g)**	**ES(d)**
finding existing items	4.41 ±0.48	5.00	4.09 ±0.47	4.00	0.22	0.83	0.05	0.23
responding to neutral UVs	4.06 ±0.42	4.00	4.62 ±0.44	5.00	2.12	**<0.04**	0.19	0.44
responding to emerging items	3.32 ±0.49	4.00	3.94 ±0.50	4.00	2.04	**<0.05**	0.17	0.42
understanding the situation	4.53 ±0.42	5.00	4.68 ±0.39	5.00	1.03	0.31	0.02	0.12
performing the subtasks well	4.82 ±0.31	5.00	4.88 ±0.38	5.00	0.83	0.41	0.00	0.06
Overall preference	4.47 ±0.31	5.00	4.59 ±0.25	5.00	1.08	0.28	0.02	0.14

Scores can range from 0 (low) to 6 (high), with higher being better

Discussion

Although the overall workload did not significantly improve, the workload-related measures from both the NASA-TLX and the objective measures did show improvement for the Full-GVA condition. Figure 40 depicts workload related metric percentage improvements of the Full-GVA condition relative to the non-GVA condition. The overall NASA-TLX workload improvement was 13% and the two workload-related objective measures, Number of Hovers and Percentage Hovering, improved 19% and 15% respectively. All of the individual NASA-TLX factors showed improvement in the Full-GVA condition. The Performance and Frustration factors both showed significant improvement of 27% for the Full-GVA condition. The remaining factors resulted in smaller improvements: Mental Demand (3%), Physical Demand (4%), Temporal Demand (8%), and Effort (10%). These improved workload measures indicate that the participants utilizing the Full-GVA condition had lower workload than those in the non-GVA condition. These measures support the hypothesis that the Full-GVA condition requires a lower workload than the non-GVA condition.

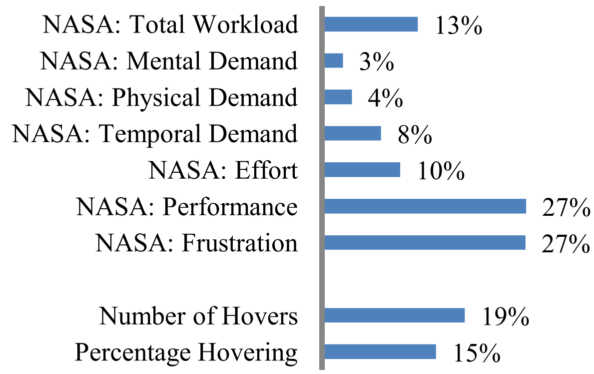


Figure 40: Graphs show the percentage improvement of the Full-GVA condition relative to the non-GVA condition for workload related metrics in two categories: NASA-TLX and objective results.

The overall 10D SART measurements for the Full-GVA condition were not statistically better, although overall SA improved 8% for this condition. Some performance measurement improvements can be argued to imply that SA increased for the Full-GVA condition; however, the relationship between SA and performance is probabilistic and not always direct and unequivocal (Endsley, 1995b). Two performance measurements, Neutral UAV Reaction (requiring SA levels 1, 2, and 3) and Bomb Reaction Time (requiring SA levels 1 and 2) were statistically significant with large improvements for the Full-GVA condition (i.e., 35% and 26% improvement, respectively). To further corroborate these two measurements, the after task questions regarding the ease of responding to neutral UVs had a 14% improvement and the emerging items resulted in a 19% improvement in the Full-GVA condition, both of these results were statistically significant. Additionally, a 3% improvement in Full-GVA condition results for the after task question related to understanding the situation. These metrics collectively imply that the Full-GVA condition improved the participants' SA.

Figure 41, similarly to Figure 40, displays the percentage improvements for SA related metrics.

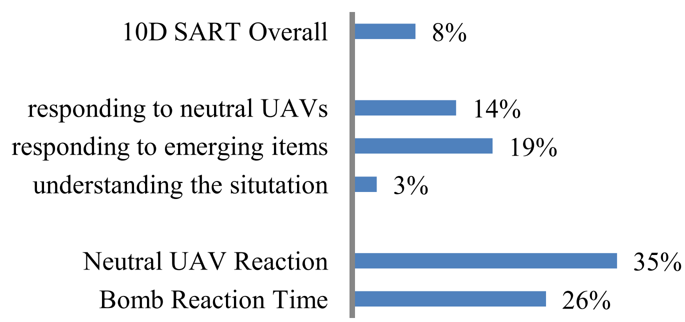


Figure 41: Graphs show the percentage improvement of the Full-GVA condition relative to the non-GVA condition for SA related metrics in three categories: 10D SART, after task questionnaires, and objective results.

The Full-GVA condition facilitated faster performance and the results were significant (Table 5). The Full-GVA condition achieved a 35% more accurate reaction to the neutral UV and a 26% faster reaction to bombs than the non-GVA condition (Figure 42).

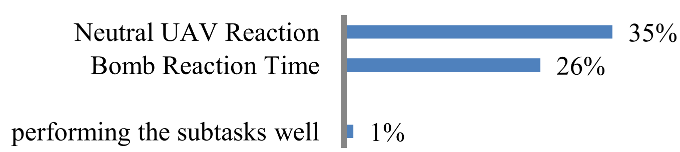


Figure 42: The percentage improvement of the Full-GVA condition relative to the non-GVA condition for performance related metrics in two categories: objective results and after task questionnaires.

The hypothesis predicted that the Full-GVA condition would be quantitatively preferred, require lower workload, improve situational awareness, and allow the participant to perform tasks at the same speed or faster. The experimental results provide support for all hypothesis components except for the quantitative preference for the Full-

GVA condition. In summary, experiment 1, the US User Level, results provide support for all hypothesis components except for one: the Full-GVA condition was not statically preferred.

Experiment 2: OC User Level

Evaluation Trial Tasks

Experiment 2 evaluated the OC User Level for monitoring the incident response progress, focusing on new hazard reports and their effect on nearby buildings in order to direct the response activities. When building information items were affected by a hazard report (i.e., the hazard impact radius intersected the building), the participant was required to click on the building information item and indicate whether to evacuate it for an explosive hazard or shelter in place until decontamination for a biological or chemical hazard. If a building was affected by both hazard types, the explosive hazard took precedence and the building was to be evacuated. There were five hazard events in each trial that occurred throughout the trial with two of one type and three of the other type (e.g., two explosives and three biological or chemical). At least 30 of about 40 total buildings required an action with a few being affected by both hazard types. The participants were informed before each trial that they would be questioned regarding an information item, which was intended to objectively measure situational awareness and to increase participant engagement.

Objective Metrics

This experiment incorporated seven objective measures. The Number of Hovers, Percentage Hovering, and In Task Question measures are identical to the respective metrics in Experiment 1. The Number of Correct Buildings represented the number of buildings correctly evacuated or quarantined in response to a hazard. The Number of Incorrect Buildings referred to the number of buildings that were incorrectly evacuated or quarantined, based on choosing the wrong option or selecting an unaffected building. The Number of Missed Buildings measured the number of buildings that were to be evacuated or quarantined that were missed. The Reaction Time to Buildings measured the average time between when the hazard first appeared and when an instruction to evacuate or quarantine the building was issued.

Results

As with the UV User Level experiment (i.e., experiment 1), all statistical analyses were two sample comparisons where the alternative hypothesis is that the Full-GVA condition is better than the non-GVA condition's values; therefore, the null hypothesis is that the Full-GVA condition is the same or worse than the non-GVA condition values (one-tailed). All statistical comparisons were Welch's *t* test for two independent unequal sample sizes with possible unequal variance (Welch, 1947). Cohen's d (ES(d)) (1988) and Hedges' g (ES(g)) (1981) effect size measures were computed.

Table 10 provides six of the seven objective measures for the OC interaction level. Four of the objective measures were highly significant, indicating that the Full-

GVA condition performed better than the non-GVA condition. The In Task Question results were inconclusive.

Table 10: The objective measurements for OC interaction level.

	Non-GVA		GVA		Comparisons			
Measurement	**M ±CI**	**Median**	**M ±CI**	**Median**	**t(66)**	**p**	**ES(g)**	**ES(d)**
Number of Hovers[1]	51.09 ±4.87	50.00	34.71 ±4.22	34.00	5.15	**<0.001**	1.45	1.21
Percentage Hovering[1]	0.35 ±0.04	0.36	0.22 ±0.03	0.21	5.88	**<0.001**	1.93	1.39
Number of Correct Buildings[2]	32.62 ±1.11	32.00	35.71 ±0.95	35.00	4.34	**<0.001**	1.01	1.01
Number of Incorrect Buildings[1]	3.35 ±0.75	3.00	0.56 ±0.19	0.50	6.49	**<0.001**	2.84	1.69
Number of Missed Buildings[1]	0.53 ±0.30	0.00	0.24 ±0.19	0.00	1.96	0.06	0.16	0.40
Reaction Time to Buildings[1,3]	17.53 ±1.03	17.26	16.90 ±0.99	19.94	1.32	0.19	0.05	0.21
In Task Question Response Speed[1]	0.89 ±0.15	1.00	1.03 ±0.16	1.00	0.28	0.78	0.09	0.30
In Task Question Accuracy[2]	1.08 ±0.24	1.00	1.00 ±0.20	1.00	0.86	0.36	0.02	0.13

[1]Lower numbers are better; [2]Higher numbers are better; [3]Time is in seconds

Two highly significant comparisons were the Number of Hover and the Percentage Hovering measures with the Full-GVA condition requiring, on average, 32% fewer hover events and 37% less time hovering than the non-GVA condition. The participants in the Full-GVA condition performed the correct action on 9% more buildings (i.e., Number of Correct Buildings) and while highly significant with a large effect size, it was not nearly as impressive as the 83% fewer incorrect actions (i.e., Number of Incorrect Buildings). The Number of Missed Buildings and Reaction Time to Buildings measures were not significant. Reacting to hazards by performing actions on buildings was the participants' only task, thus allowing participants to be attuned to reacting to events, which may explain why no significant difference in reaction times was found.

The weighted NASA-TLX (Hart & Staveland, 1988) overall workload was not statistically significant (Table 11). The non-GVA condition had, an average, an overall workload of 51.45 ±6.05 versus 45.25 ±5.36 for the Full-GVA condition, a 12%

reduction. The Full-GVA condition frustration factor was, on average, 39% lower than the non-GVA condition (20.44 ±5.24 versus 33.68 ±7.13), a significant difference ($p < 0.01$, $t(66) = 3.17$, ES(g) = 0.50, ES(d) = 0.71).

Table 11: The NASA-TLX workload analysis results for the OC User Level.

	Non-GVA		GVA		Comparisons			
Measurement	M ±CI	Median	M ±CI	Median	t(66)	p	ES(g)	ES(d)
Mental Demand	59.5 ±7.776	65.00	56.47 ±6.97	60.00	1.09	0.28	0.02	0.14
Physical Demand	27.21 ±8.28	17.50	25.59 ±7.63	15.00	0.87	0.39	0.05	0.23
Temporal Demand	62.65 ±8.26	70.00	56.91 ±8.37	62.50	1.38	0.17	0.05	0.23
Performance	30.15 ±6.51	20.00	25.29 ±5.72	25.00	1.50	0.14	0.07	0.27
Effort	52.21 ±6.80	52.50	51.18 ±7.44	50.00	0.81	0.42	0.00	0.05
Frustration	33.68 ±7.13	25.00	20.44 ±5.24	15.00	3.17	**<0.01**	0.50	0.71
Total Workload	51.45 ±6.05	55.50	45.25 ±5.36	47.17	1.85	0.07	0.13	0.37

Percentages from 0 (low) to 100 (high), with lower being better

None of the MRQ results were statistically significant, but the results are presented in Table 12.

Table 12: The MRQ results for the OC User Level.

Measurement	Non-GVA M ±CI	GVA M ±CI	Comparisons t(66)	p	ES(g)	ES(d)
Auditory Emotional	0.26 ±0.25	0.09 ±0.17	0.22	0.83	0.05	0.23
Auditory Linguistic	0.18 ±0.17	0.18 ±0.21	0.68	0.50	0.00	0.00
Facial Figural	0.18 ±0.17	0.18 ±0.21	0.68	0.50	0.00	0.00
Facial Motive	0.12 ±0.11	0.29 ±0.26	0.14	0.89	0.09	0.30
Manual	1.97 ±0.39	2.15 ±0.38	1.13	0.26	0.02	0.15
Short Term Memory	2.59 ±0.35	2.50 ±0.28	0.94	0.35	0.01	0.09
Spatial Attentive	2.97 ±0.33	3.03 ±0.25	0.86	0.39	0.00	0.07
Spatial Categorical	2.41 ±0.33	2.41 ±0.33	0.68	0.50	0.00	0.00
Spatial Concentrative	2.76 ±0.33	2.74 ±0.37	0.75	0.45	0.00	0.03
Spatial Emergent	2.91 ±0.36	3.00 ±0.31	0.92	0.36	0.01	0.09
Spatial Positional	2.71 ±0.35	2.74 ±0.29	0.76	0.45	0.00	0.03
Spatial Quantitative	2.06 ±0.38	1.71 ±0.39	1.65	0.10	0.09	0.31
Tactile Figural	0.38 ±0.37	0.26 ±0.25	0.35	0.73	0.02	0.15
Visual Lexical	2.09 ±0.29	1.91 ±0.37	1.20	0.23	0.03	0.18
Visual Phonetic	0.68 ±0.34	0.91 ±0.43	0.26	0.80	0.04	0.20
Visual Temporal	1.38 ±0.39	1.53 ±0.42	1.03	0.31	0.01	0.12
Vocal	0.03 ±0.06	0.00 ±0.00	1.41	0.16	0.06	0.24

[1]Scores can range from 0 to 4. Higher indicates more workload.

The 10D SART overall SA for the Full-GVA condition was 6% greater than the non-GVA condition (16.71 ±1.42 versus 15.71 ±1.47); however, this difference is not statistically significant (Table 13). As can be seen in Table 13, none of the 10D SART subcomponents were statistically significant.

Table 13: The 10D SART analysis results for the OC User Level.

Measurement	Non-GVA		GVA		Comparisons			
	M ±CI	Median	M ±CI	Median	t(66)	p	ES(g)	ES(d)
Instability[1,3]	4.56 ±0.45	5.00	4.09 ±0.46	4.00	1.79	0.08	0.12	0.35
Variability[1,3]	4.71 ±0.42	5.00	4.15 ±0.52	4.50	1.97	0.05	0.15	0.40
Complexity[1,3]	4.47 ±0.45	5.00	4.24 ±0.45	4.50	1.20	0.23	0.03	0.18
Readiness[1,4]	4.44 ±0.37	4.00	4.41 ±0.54	5.00	0.62	0.54	0.00	0.02
Mental Capacity[1,4]	4.29 ±0.38	4.00	3.47 ±0.51	4.00	0.01	0.99	0.37	0.61
Concentration[1,4]	4.41 ±0.32	5.00	4.29 ±0.51	4.50	0.46	0.65	0.01	0.09
Focus[1,4]	4.00 ±0.48	4.00	3.76 ±0.50	4.00	0.33	0.74	0.03	0.16
Info Quantity[1,4]	4.53 ±0.44	5.00	4.56 ±0.34	5.00	0.74	0.46	0.00	0.03
Info Quality[1,4]	4.21 ±0.40	4.50	4.59 ±0.34	5.00	1.77	0.08	0.12	0.34
Familiarity[1,4]	3.56 ±0.50	4.00	4.09 ±0.43	4.00	1.91	0.06	0.14	0.38
Overall SA[2,4]	15.71 ±1.47	16.00	16.71 ±1.42	16.00	1.38	0.17	0.05	0.23

[1]Scores can range from 0 to 4. [2]Scores can range from -18. [3]Lower is better. [4]Higher is better.

The post-task questionnaire assessed the ease of responding to emerging items, understanding the situation, performing the subtasks well, and using the visualization overall (Table 14). The overall ease of using the visualization for the Full-GVA condition was, on average, 10% easier to use overall than the non-GVA condition, which was significant. The other three questions were not significant, although they all showed improvement for the Full-GVA condition.

Table 14: After Task Questionnaire for the OC User Level.

Ease of …	Non-GVA		GVA		Comparisons			
	M ±CI	Median	M ±CI	Median	t(66)	p	ES(g)	ES(d)
responding to emerging items[1]	3.71 ±0.49	4.00	4.09 ±0.47	4.00	1.50	0.14	0.07	0.27
understanding the situtation[1]	4.82 ±0.25	5.00	4.97 ±0.21	5.00	1.31	0.19	0.04	0.21
performing the subtasks well[1]	4.79 ±0.28	5.00	5.00 ±0.23	5.00	1.50	0.14	0.07	0.27
Overall perference[1]	4.56 ±0.26	4.50	5.03 ±0.27	5.00	2.71	**<0.01**	0.35	0.60

[1]Scores can range from 0 (low) to 6 (high), with higher being better

Discussion

Although the overall workload metric did not significantly improve across conditions, both the NASA-TLX and the objective measures did show improvement for the Full-GVA condition over the non-GVA condition. Figure 43, similarly to Figure 40 for the US User Level, displays the percentage improvements for workload related metrics. The overall NASA-TLX workload improvement was 12% and the two workload-related objective measures, Number of Hovers and Percentage Hovering, improved 32% and 38% respectively. All of the individual NASA-TLX factors showed improvement in the Full-GVA condition. The Performance and Frustration factors showed significant improvement of 16% and 39%, respectively, for the Full-GVA condition. The remaining factors resulted in smaller improvements: Mental Demand (5%), Physical Demand (6%), Temporal Demand (9%), and Effort (2%). The improved subjective and objective workload measures, in total, indicate that the Full-GVA condition participants had lower workload than the participants in the non-GVA condition.

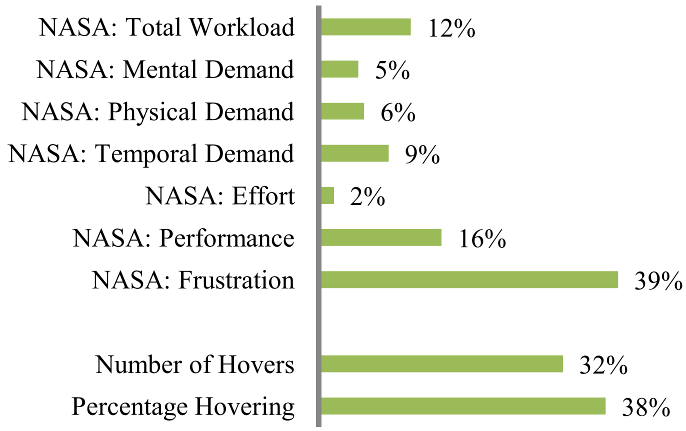


Figure 43: Graphs show the percentage improvement for the Full-GVA condition relative to the non-GVA condition for workload related metrics in two categories: NASA-TLX and objective results.

Figure 44 demonstrates that all SA metrics were better in the Full-GVA condition. The 10D SART overall measurement resulted in a 6% improvement for the Full-GVA condition. Similarly, the after task questions regarding the ease of responding to emerging items (10%) and understanding the situation (19%) improved. All four SA related performance measurements also improved for the Full-GVA condition: Number of Correct Buildings (9%), Number of Incorrect Buildings (83%), Number of Missed Buildings (56%), and Reaction time to Buildings (4%). The improvements in the number of correct and incorrect buildings were significant. Even though the percentage improvement in the Number of Missed Buildings was large, it was not significant. The number of occurrences of missed buildings was very low (i.e., less than one, on average) and this may have resulted in no significant difference between conditions. The subjective SA measurements, overall SA and the after task questions “ease of responding to emerging items” and “understanding the situation,” all indicated that the Full-GVA condition was an improvement, but the improvements were not significant. While some objective measures in were significant, they cannot be corroborated by the subjective measures, which were not significant; therefore, these results do not provide sufficient support to prove that for the OC User Level the Full-GVA condition provided a SA improvement.

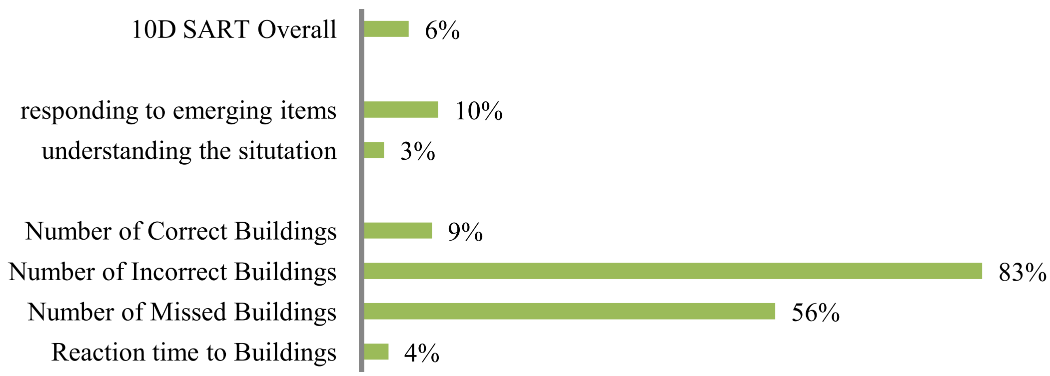


Figure 44: Graphs show the percentage improvement for the Full-GVA condition relative to the non-GVA condition for SA related metrics in three categories: 10D SART, after task questionnaires, and objective results.

Reaction times showed only a 4% improvement in the reaction speed to buildings (Figure 45). However, the reaction speed is not independent of the number correct and incorrect building actions. The participants, in the non-GVA condition, on average interacted with 35.97 buildings; whereas, the participants in the Full-GVA condition, on average, interacted with 36.27 buildings, a slightly larger number. If the reaction speed is equal between the two conditions, the Full-GVA condition should have a slightly slower average reaction time because the participants interacted with more buildings. However, the full GVA condition actually had a slightly *faster* average reaction time, meaning that in spite of the participants interacting with more buildings, they interacted with each building faster. Furthermore, the number of incorrect buildings and missed buildings greatly improved, implying that even though the Full-GVA condition had only modest reaction time improvement, the participants reacted, on average, more correctly.

Therefore, the evidence supports the hypothesis that the Full-GVA condition is the same or faster than the non-GVA condition.

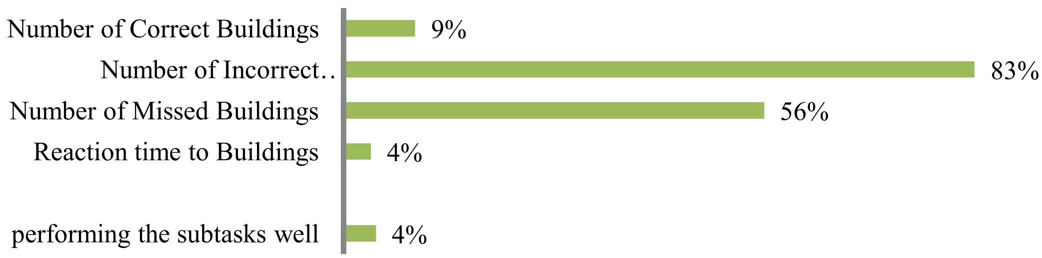


Figure 45: The percentage improvement for the Full-GVA condition relative to the non-GVA condition for performance related metrics in two categories: objective results and after task questionnaires.

The hypothesis predicted that the Full-GVA condition would be quantitatively preferred, require lower workload, improve situational awareness, and allow the participant to perform tasks at the same speed or faster. The experimental results provide support for all hypothesis components except for the quantitative preference for the Full-GVA condition. In summary, experiment 2 (i.e., the OC User Level) results provide support for all hypothesis components except that the Full-GVA condition did not statistically improve overall SA.

General Discussion

Both experiments provide support for all hypothesis components except for two: in experiment 1 (i.e., the US User Level), the Full-GVA condition was not quantitatively preferred and in experiment 2 (i.e., the US User Level) the Full-GVA condition did not improve overall SA. The hypothesis prediction that the Full-GVA condition would be quantitatively preferred was statistically valid for the OC User Level only (Table 14). The participants quantitatively preferred the Full-GVA condition, on average, for the US User Level, but the difference was not significant (Table 9). One possible reason that the Full-GVA condition preference was not significant was that the participants' answers indicated that the Full-GVA condition was harder to use when finding existing items (Table 14). The GVA algorithm, by design, deemphasizes existing information items that are determined to be unimportant (i.e., not historically or currently relevant) by reducing their visual size to residue, which means that those items are harder to find *intentionally*. This deemphasizing of information items is a main difference between the full GVA and the non-GVA conditions. Furthermore, it is possible that participants' familiarity with maps, including digital maps (e.g., Microsoft Maps, Google Maps), that display information items in a similar manner as the non-GVA condition caused some predisposed bias against the Full-GVA condition.

The overall SA metrics were not significant for either User Level, which may be an artifact of the 10D SART. The 10D SART computes an overall SA metric, but does not require participants to provide an overall SA value. The 3D SART does include an overall SA question and has been used in previous evaluations with good success at achieving statistical significance for situations that had the approximately the same effect size (i.e., ES(g) ≈ 0.05 and ES(g) ≈ 0.26) implying that the 10D SART may have less statistical power (Humphrey & Adams, 2008; Humphrey et al., 2006). The US User Level SA improvement was supported through other metrics (see Experiment 1, Discussion); however, the OC User Level metrics were not sufficiently supported.

Both User Level results indicated that the Full-GVA condition lowered workload by requiring less interaction (Table 5 and Table 10). These decreases, by themselves, may have been undesirable since they can indicate a lack of focus or a loss of vigilance. However, when these decreases are coupled with the positive improvement in performance (e.g., faster bomb reaction, more correct building actions) they indicate that with less interaction, the participants at both User Levels achieved better performance.

Second Evaluation: Within-subjects Design

Method

The first evaluation focused on the overall effectiveness of the GVA algorithm compared to not using it across different types of tasks and different user interaction roles or User Levels (see Chapter IV). The second evaluation focused on the contributions of the GVA algorithm's two information classes, historically and currently relevance and novel and emerging, and their improvements across time. The CBRNE incident response domain provided the context and the tasks were based on a real CBRNE response scenario (see Chapter III). The GVA algorithm implementation was evaluated at the US User Level, which represents an individual who commands the UVs by providing tasks and goals to be accomplished, that is, an operator/supervisor human-robot interaction role.

The experiment employed a within-subjects design and tested four user interface conditions: not employing the GVA algorithm (i.e., the non-GVA condition), employing only the novel and emerging information class of the GVA algorithm (i.e., the NE condition), employing only the historically and currently relevant information class of the GVA algorithm (i.e., the HC condition), and employing the full GVA algorithm (i.e., the

Full-GVA condition). The within-subjects design for this evaluation allowed participants to compare the conditions and, therefore, provided better subjective results than the previous study. However, a within-subjects design is susceptible to crossover and learning effects that may hinder the objective measures results. Since this user evaluation focused on ascertaining the contributions of the GVA algorithm subcomponents as perceived by the participants, the within-subjects design was chosen to improve the subjective measures results.

Each participant received a system overview, performed one training trial, and then eight evaluation trials, two for each condition. The ordering of the conditions was counterbalanced based on a Latin square design so that all four conditions occurred once each before the conditions were repeated. Both the training and the evaluation trials lasted approximately four minutes each.

Participants

Thirty-two participants completed the evaluation and were compensated $25 USD. The evaluation lasted approximately one hour and fifty minutes. All participants were at least 18 years of age. Participants were screened for four requirements: at least a high school education, computer competency, English competency, no experience with the experimental maps, and no prior exposure to the interface including any previous experiments. All participants had normal or corrected-to-normal vision including not being color-blind and were not required to have domain specific knowledge (i.e., CBRNE incident response knowledge). The participants performed each visual condition twice for a total of eight tasks, with the presentation order being counterbalanced.

Hypothesis

The experimental **hypothesis** was that the Full-GVA condition would be quantitatively preferred over the other three conditions and that the non-GVA condition would have higher workload, worse situational awareness, and slower performance times than the GVA related conditions (i.e., NE, HC, or Full-GVA conditions).

Procedure

Each participant completed a consent form and background/screening questionnaire. The participants were given an oral explanation regarding the interface layout, interaction with the interface, each type of information icon they would encounter, and the structure and nature of the tasks they were to perform. The participants completed a training trial, then one round of experimental trials (i.e., one trial for each of the four conditions), and then a second round. The training trial was a simpler version of the evaluation trials. After each experimental trial, participants completed questionnaires assessing situational awareness, workload, and preferences.

Three unique environments were developed, one for the training trial and one for each round of trials. All trials were based on a realistic CBRNE scenario involving a train derailment precipitated incident (see Chapter III).

Evaluation Trial Tasks

Each evaluation trial incorporated four primary tasks. These primary tasks were identical to the tasks in the first evaluation's experiment 1. The first task assigned several scene survey tasks based on existing and newly added information items and was motivated by a short narrative. The second task required reacting to newly appearing explosive hazards by assigning a UV investigation task to the vicinity of the hazard. Each trial contained two explosives that appeared at different times. This task required situational awareness levels 1 and 2 (i.e., detection and comprehension) and vigilance. The third task required stopping neutral UVs if their current trajectory would send them into the same area as the participant's UVs. Each trial contained two neutral UVs that appeared and required stopping at different times. This task required situational awareness levels 1, 2, and 3 (i.e., projection), since projection of the neutral UV's path was required in order to determine when to stop its motion. The last task required answering a question relating to a single information item towards the task's completion. The participants were told that they would receive such a question, which was intended to objectively measure situational awareness and increase participant engagement.

Data collection and Metrics

The experiment was a 4 x 2 within-subjects design with the visual condition (i.e., non-GVA, NE, HC, or Full-GVA) and the round (i.e., 1 or 2) as independent variables. The evaluation's dependent variables include a number of objective and subjective measures.

This experiment incorporated eight objective measures. The Number of Hovers measured the number of mouse hover events. Percentage Hovering represented the percentage of time spent hovering over an information item, where hovering is defined as the mouse cursor being positioned over an information item. The Unique Hovers measures the number of unique information items that were hovered over. The Stopped Neutral Time measured the time at which the neutral UV was stopped relative to the last acceptable stop time (i.e., a value of zero, which was calculated geometrically). Negative Stopped Neutral times indicated that the participant stopped the neutral UV late (i.e., after it entered their area), whereas positive times indicated that the participant stopped the neutral UV early (i.e., before the last acceptable time). The Bomb Reaction Time represented the reaction time between when a bomb first appeared and when a bomb identification task was created. The Number of Bomb Misses referred to the number of bomb information items for which no identification task was assigned. The Number of Missed Neutral referred to the number of neutral UVs that were not stopped. Finally, the In Task Question objective measure recorded the time to respond to the verbal SA question.

This experiment employed four post-trial subjective questionnaires to ascertain perceived SA, perceived workload, and preferences. Subjective SA was measured using the 10D SART. Subjective workload was measured using the NASA-TLX, and the MRQ. A post-experiment questionnaire ascertained participants' thoughts regarding each visual condition's utility. After all trials, a post-experiment questionnaire asked the participants to directly rank (i.e., from best to worst) the visual conditions for a series of questions. These questions were the ease of: finding existing items, responding to neutral UVs, responding to emerging items, understanding the situation, performing the subtasks well, and using the visualization overall.

Experiment 3: GVA Components and Learning

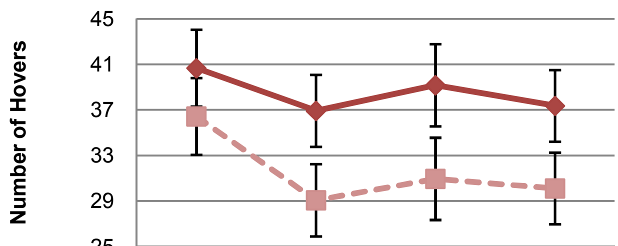
The statistical analyses for the objective metrics and post-trial subjective questionnaires were repeated measured ANOVAs with means and 95% confidence intervals reported. The post-experiment questionnaire, which asked the participant to rank the visual conditions, employed the non-parametric paired rank order Friedman test (Hollander & Wolfe, 1999) to ascertain if the visual condition had significant effect on the question results. Multiple pairwise comparisons were performed using the Bonferroni corrected Nemenyi procedure (Nemenyi, 1963) for the post-experiment questionnaire.

Objective Measures Results

There were eight objective measures. The three hover related measures (i.e., Number of Hovers, Percentage Hovering, and Unique Hovers) were each significant for both main effects, visual condition and round, and not significant for the interaction between visual condition and round.

The Number of Hovers was significant for the main effects of visual condition ($F(3, 233) = 4.20$, $p < 0.01$) and round ($F(1, 233) = 38.09$, $p < 0.0001$). Figure 46 provides the mean and 95% confidence intervals for the Number of Hovers across all visual conditions and rounds. When comparing the non-GVA to the other conditions, the

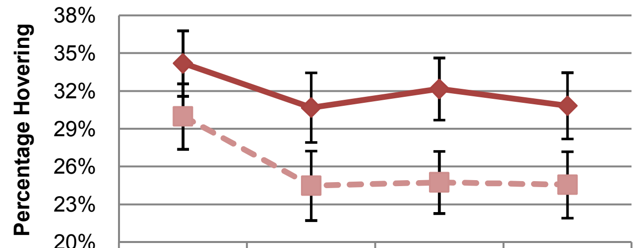
Number of Hovers was higher than any GVA related condition for both rounds; whereas, the NE condition had the least Number of Hovers in both rounds. All visual conditions experienced fewer hovering events in the second round; however, the non-GVA condition improved 10.4%, the least versus a 20.6 ±1.1% average improvement for the GVA conditions.



	non-GVA	NE	HC	Full-GVA
R1	40.664	36.915	39.166	37.354
R2	36.420	29.059	30.940	30.101

Figure 46: The average Number of Hovers depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals.

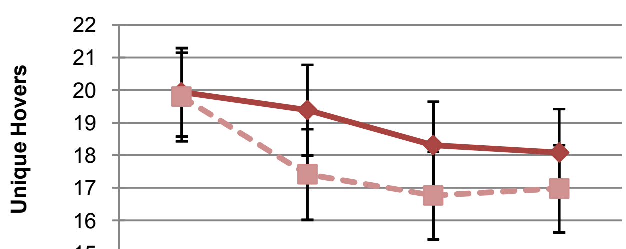
The Percentage Hovering (i.e., the percent of time spent hovering) had significant main effects for visual condition ($F(3, 233) = 6.072$, $p < 0.001$) as seen in Figure 47. The non-GVA condition had the highest Percentage Hovering in both rounds. The NE and Full-GVA conditions were essentially tied for lowest Percentage Hovering in both rounds, while the HC condition was higher in the first round and essentially tied for first in the second round. All visual conditions experienced a significantly lower Percentage Hovering in the second round ($F(1, 233) = 51.93$, $p < 0.0001$); however, the non-GVA condition improved the least (12.2%) as compared to the GVA related conditions (21.3 ±1.9%). These results were very similar to the results reported for the Number of Hovers.



	non-GVA	NE	HC	Full-GVA
R1	0.342	0.307	0.322	0.308
R2	0.300	0.245	0.247	0.245

Figure 47: The average Percentage Hovering depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals.

The Unique Hovers, or the number of unique information items hovered over, had a significant main effects for visual condition ($F(3, 233) = 5.819$, $p < 0.001$). The non-GVA condition had the most Unique Hovers in both rounds (Figure 48). The Full-GVA condition had the lowest number of Unique Hovers in the first round, and had the second least in the second round. The HC condition was slightly lower than the Full-GVA condition during the second round. All visual conditions *except* the non-GVA condition improved significantly between rounds ($F(1, 233) = 8.739$, $p < 0.01$); 0% versus 8.2 ±2.3%.



	non-GVA	NE	HC	Full-GVA
R1	19.940	19.393	18.316	18.091
R2	19.800	17.422	16.772	16.983

Figure 48: The average Unique Hovers depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals.

The Stopped Neutral Time, or the time at which the neutral UV was stopped relative to the last acceptable stop time, had a significant main effect for visual condition ($F(3, 368) = 3.63$, $p < 0.01$), but the main effect for round was not significant (Figure 49). During round one, the HC and Full-GVA condition averages are the closest to zero without being more than one second late. For the second round, again the HC and Full-GVA conditions had the best times; however, both were approximately two seconds worse than they were in round one. Observationally, the participants during the second round were generally monitoring the neutral UVs more frequently and it appeared that the participants' became impatient and stop the UVs earlier than necessary. They may have stopped the neutral UVs earlier as there were not any direct negative consequences for doing so.

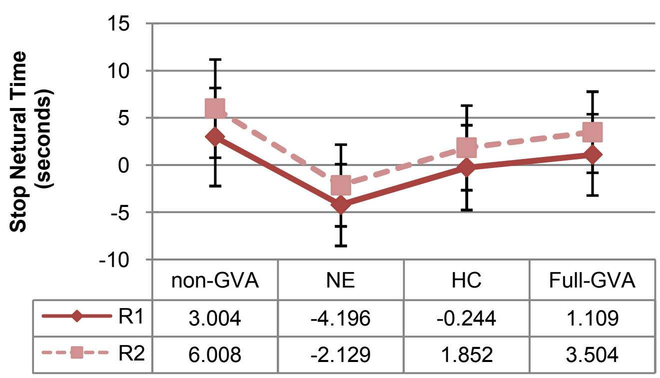


Figure 49: The average Stop Neutral Time depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Positive and closer to zero is better.

The analysis of the Bomb Reaction Time, the Number of Bomb Misses, the Number of Missed Neutral, and the In Task Question found no significant results for both main effects (i.e., visual condition and round) and the interaction of visual condition and round. Table 15 provides these results.

Table 15: Non significant Objective Measure Results

		M ±CI				Visual Condition		Round		Interaction	
Measurement	**Round**	**non-GVA**	**NE**	**HC**	**Full-GVA**	**F**	**p**	**F**	**p**	**F**	**p**
Bomb Reaction Time[1]	1	6.87 ±2.16	6.51 ±2.33	7.33 ±1.49	7.64 ±2.36	F(3,456)=0.18	0.91	F(1,456)=2.78	0.1	F(3,456)=0.22	0.88
	2	5.18 ±1.21	6.47 ±2.93	6.02 ±1.87	5.55 ±2.24						
Missed Bombs[1]	1	0.02 ±0.03	0.05 ±0.06	0.02 ±0.03	0.00 ±0.00	F(3,488)=0.950	0.420	F(1,488)=2.51	0.110	F(3,488)=0.08	0.97
	2	0.06 ±0.06	0.08 ±0.07	0.06 ±0.06	0.05 ±0.05						
Missed Stopping a Neutral UV[2]	1	0.05 ±0.05	0.02 ±0.03	0.00 ±0.00	0.02 ±0.03	F(3,488)=0.416	0.740	F(1,488)=0.07	0.79	F(3,488)=1.65	0.18
	2	0.00 ±0.00	0.05 ±0.05	0.02 ±0.03	0.02 ±0.03						
In Task Question Response Speed[1]	1	1.03 ±0.04	0.97 ±0.03	1.00 ±0.05	1.00 ±0.05	F(3,233)=0.58	0.63	F(1,233)=0.06	0.81	F(3,233)=0.72	0.54
	2	1.00 ±0.05	1.03 ±0.03	0.97 ±0.04	1.00 ±0.03						
In Task Question Accuracy[2]	1	0.95 ±0.04	1.00 ±0.00	0.97 ±0.03	0.97 ±0.03	F(3,233)=0.54	0.66	F(1,233)=0.09	0.77	F(3,233)=0.20	0.91
	2	0.95 ±0.04	0.97 ±0.03	0.98 ±0.03	0.98 ±0.02						

[1]Lower numbers are better; [2]Higher numbers are better

Subjective Measures Results

There were four post-trial subjective questionnaires: NASA-TLX, MRQ, 10D SART, and the post-trial questionnaire. The weighted NASA-TLX overall workload main effect of visual condition was not significant, but the main effect of round was ($F(1, 232) = 12.059$, $p < 0.001$). During round one, the non-GVA condition had a lower workload than any other visual condition by 9.6 ±1.3% (Figure 50). However, during the second round the non-GVA condition did not improve and became the condition with the highest workload by 5.0 ±3.4%. On average, the GVA conditions improved by 12.7 ±2.3% across rounds.

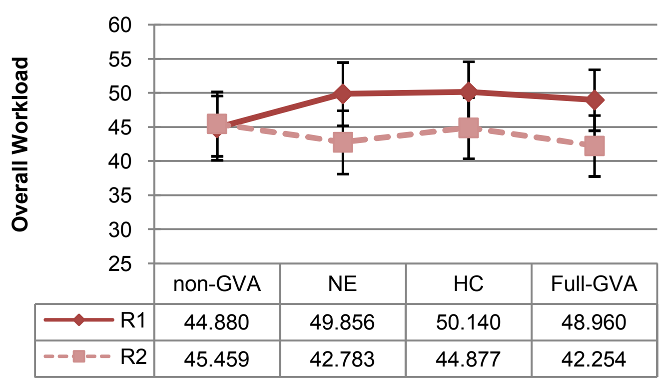
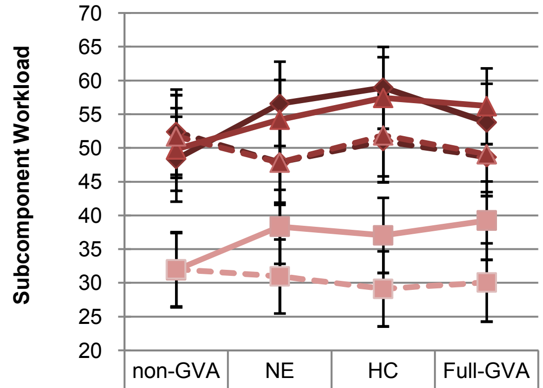


Figure 50: The weighted NASA-TLX overall workload depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Lower is better.

None of the NASA-TLX subcomponents had a significant main effect for visual condition, or the visual condition by round interaction. Three subcomponents had a significant main effect for round: Mental Demand ($F(1, 232) = 5.276$, $p = 0.02$), Temporal Demand ($F(1, 232) = 4.783$, $p = 0.03$), and Frustration ($F(1, 232) = 12.017$, $p < 0.001$). Figure 51 shows that these components had the same between round improvements as the overall workload; that is, the non-GVA condition was better in round one, did not improve between rounds, and therefore became the worst.



	non-GVA	NE	HC	Full-GVA
Mental R1	48.353	56.568	58.936	53.790
Mental R2	52.360	47.855	51.006	48.640
Temporal R1	49.802	54.186	57.406	56.202
Temporal R2	51.722	47.841	51.879	49.092
Frustration R1	31.898	38.336	37.053	39.255
Frustration R2	32.020	30.967	29.122	30.082

Figure 51: The NASA-TLX Mental Demand (diamond symbol), Temporal Demand (triangle), and Frustration (square) workload depicted by visual condition and round (solid line: R1, dashed line: R2) with 95% confidence intervals. Lower is better.

The Performance subcomponent also had a significant main effect for round (F(1, 232) = 25.674, p < 0.0001); however, it did not have the same between round improvement characteristic because all conditions *including* the non-GVA condition improved on average 18.7 ±4.8% between rounds; whereas in most metrics the non-GVA condition did not improve. The remaining two workload subcomponents, Physical Demand and Effort were not significant for either main effects or interaction and their results are provided in None of the NASA-TLX subcomponents had a significant main effect for visual condition, or the visual condition by round interaction. Three subcomponents had a significant main effect for round: Mental Demand (F(1, 232) = 5.276, p = 0.02), Temporal Demand (F(1, 232) = 4.783, p = 0.03), and Frustration (F(1, 232) = 12.017, p < 0.001). Figure 51 shows that these components had the same between round improvements as the overall workload; that is, the non-GVA condition was better in round one, did not improve between rounds, and therefore became the worst..

Table 16: NASA-TLX Insignificant Results

Measurement	Round	M ±CI non-GVA	M ±CI NE	M ±CI HC	M ±CI Full-GVA	Visual Condition F(3, 234)	Visual Condition p	Round F(1, 234)	Round p	Interaction F(3, 234)	Interaction p
Physical Demand	1	26.26 ±6.00	24.99 ±6.00	27.41 ±6.07	25.12 ±5.76	1.16	0.33	0.356	0.55	0.36	0.78
	2	27.42 ±5.97	24.51 ±6.12	26.97 ±5.87	21.90 ±5.91						
Effort	1	41.58 ±6.13	48.76 ±5.93	48.20 ±6.06	47.70 ±5.61	0.60	0.61	2.67	0.10	2.12	0.10
	2	45.00 ±5.87	42.78 ±6.01	45.78 ±5.91	40.19 ±5.52						

Lower numbers are better

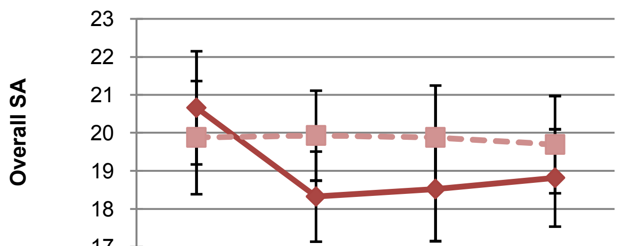
None of the MRQ elements were significant for both main effects (i.e., visual condition and round) or the interaction between the visual condition and the round. The MRQ results are provided in Table 17.

Table 17: MRQ Results

Measurement	Round	M ±CI				Visual Condition		Round		Interaction	
		non-GVA	NE	HC	Full-GVA	F(3,234)	p	F(1,234)	P	F(3,234)	p
Short Term Memory	1	2.95 ±0.27	3.19 ±0.26	3.06 ±0.36	3.06 ±0.31	0.49	0.69	0.34	0.56	0.59	0.62
	2	3.09 ±0.29	3.06 ±0.35	2.97 ±0.31	3.06 ±0.35						
Spatial Attentive	1	3.65 ±0.36	3.85 ±0.34	3.91 ±0.34	3.66 ±0.40	1.10	0.35	4.39	0.04	0.22	0.88
	2	3.61 ±0.42	3.62 ±0.35	3.71 ±0.31	3.50 ±0.31						
Spatial Categorical	1	3.24 ±0.36	3.22 ±0.39	3.25 ±0.40	3.21 ±0.39	0.51	0.70	0.04	0.85	0.28	0.84
	2	3.19 ±0.29	3.25 ±0.26	3.42 ±0.31	3.19 ±0.42						
Spatial Concentrative	1	3.34 ±0.36	3.41 ±0.34	3.16 ±0.41	3.39 ±0.31	0.79	0.50	1.79	0.18	1.97	0.12
	2	3.72 ±0.33	3.35 ±0.33	3.60 ±0.38	3.22 ±0.42						
Spatial Emergent	1	3.53 ±0.34	3.40 ±0.39	3.59 ±0.45	3.67 ±0.41	0.99	0.40	1.02	0.31	1.13	0.34
	2	3.98 ±0.33	3.54 ±0.29	3.66 ±0.40	3.60 ±0.33						
Spatial Positional	1	3.61 ±0.37	3.40 ±0.29	3.46 ±0.35	3.24 ±0.36	0.97	0.41	2.89	0.09	1.50	0.22
	2	3.36 ±0.31	3.18 ±0.35	3.23 ±0.37	3.43 ±0.34						
Spatial Quantitative	1	2.70 ±0.42	2.73 ±0.37	2.91 ±0.40	2.56 ±0.34	1.76	0.16	0.43	0.51	0.58	0.63
	2	2.94 ±0.38	2.67 ±0.40	2.85 ±0.37	2.63 ±0.34						
Visual Lexical	1	3.33 ±0.38	3.36 ±0.42	3.18 ±0.43	3.13 ±0.36	1.29	0.28	3.64	0.06	1.53	0.21
	2	3.27 ±0.41	2.96 ±0.43	3.24 ±0.42	3.02 ±0.41						
Visual Temporal	1	2.96 ±0.37	3.02 ±0.37	2.89 ±0.38	2.97 ±0.43	0.62	0.61	1.46	0.23	1.3	0.27
	2	3.04 ±0.40	2.77 ±0.38	2.95 ±0.35	2.69 ±0.33						

Lower is better

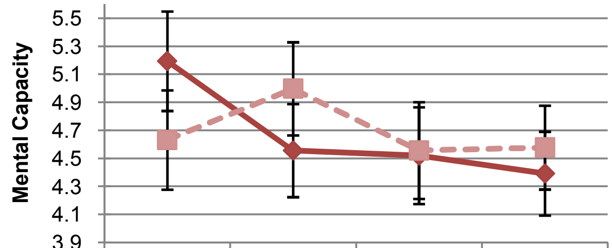
Three of the 10D SART subcomponents had one significant main effect; however, the rest of the subcomponents and the overall 10D SART were not significant for both main effects (i.e., visual condition and round) and the interaction of visual condition and round. The overall 10D SART did, however, display the same characteristics with respect to between round improvements as did many of the workload subcomponents (Figure 52). The similarities were that the non-GVA condition was the best in round one and then did not improve between rounds (in this case became worse). However, the GVA related conditions did improve causing the NE and the HC conditions to be better or the same as the non-GVA condition in the second round.



	non-GVA	NE	HC	Full-GVA
R1	20.661	18.328	18.523	18.819
R2	19.880	19.933	19.880	19.697

Figure 52: The 10D SART overall SA depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

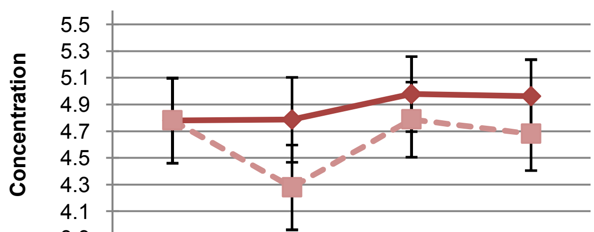
The 10D SART Mental Capacity subcomponent was significant for the visual condition ($F(1, 234) = 2.814$, $p = 0.04$) and for the interaction between the visual condition and round ($F(1, 234) = 2.955$, $p = 0.03$) (Figure 53). The non-GVA condition is the only condition not to improve and actually become worse between rounds (10.8% worse). The HC condition essentially did not improve also, yet the other two conditions did improve (i.e., NE: 9.6%, Full-GVA: 4.2%).



	non-GVA	NE	HC	Full-GVA
R1	5.194	4.556	4.521	4.393
R2	4.632	4.997	4.557	4.578

Figure 53: The 10D SART Mental Capacity depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

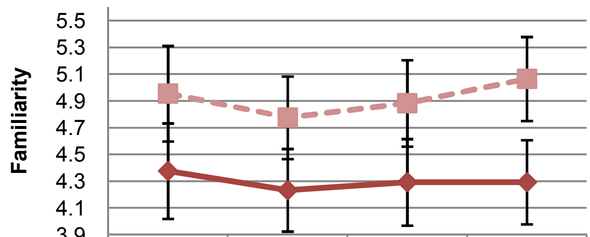
The 10D SART Concentration subcomponent had a significant main effect for round ($F(1, 234) = 4.450$, $p = 0.04$) only (Figure 54). This subcomponent displayed similar between round characteristic to many of the workload metrics (i.e., the non-GVA condition results did not change between rounds). However, during the second round the GVA related conditions became worse by 6.7 ±3.9% on average.



	non-GVA	NE	HC	Full-GVA
R1	4.781	4.787	4.979	4.963
R2	4.781	4.281	4.788	4.682

Figure 54: The 10D SART Concentration depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

The 10D SART Familiarity subcomponent had a significant main effect for round ($F(1, 234) = 32.662$, $p < 0.0001$) only and all four conditions improved on average 14.4 ±2.6% (Figure 55). The non-GVA condition was the most familiar in the first round and then lost to the Full-GVA in the second round. The insignificant subcomponent results are provided in Table 18.



	non-GVA	NE	HC	Full-GVA
R1	4.377	4.234	4.293	4.294
R2	4.955	4.775	4.882	5.064

Figure 55: The 10D SART Familiarity depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

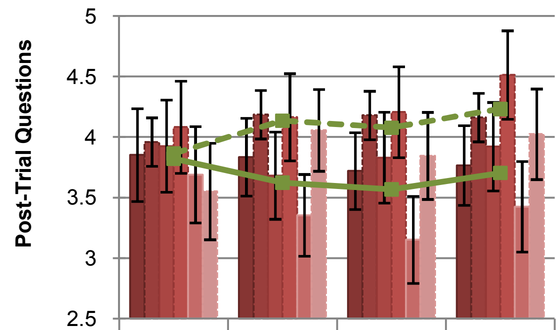
Table 18: 10D SART Results

Measurement	Round	M ±CI				Visual Condition		Round		Interaction	
		non-GVA	NE	HC	Full-GVA	F(3,234)	P	F(1,234)	p	F(3,234)	p
Instability[1]	1	3.87 ±0.35	4.72 ±0.33	4.67 ±0.30	4.24 ±0.30	0.71	0.54	0.05	0.83	0.63	0.60
	2	4.67 ±0.31	3.88 ±0.31	4.44 ±0.32	4.46 ±0.34						
Variability[1]	1	4.37 ±0.32	5.01 ±0.32	4.99 ±0.28	4.82 ±0.27	0.94	0.42	2.49	0.12	1.04	0.38
	2	4.82 ±0.31	4.23 ±0.33	4.73 ±0.29	4.76 ±0.31						
Complexity[1]	1	4.28 ±0.30	4.61 ±0.29	4.63 ±0.27	4.55 ±0.30	1.26	0.29	0.03	0.86	1.32	0.27
	2	4.48 ±0.30	4.14 ±0.30	4.72 ±0.31	4.63 ±0.29						
Readiness[2]	1	4.70 ±0.32	4.66 ±0.36	4.59 ±0.29	4.65 ±0.29	0.27	0.85	0.16	0.68	0.17	0.92
	2	4.74 ±0.31	4.53 ±0.31	4.69 ±0.23	4.62 ±0.35						
Focus[2]	1	4.40 ±0.29	5.07 ±0.37	4.90 ±0.25	4.86 ±0.33	1.34	0.26	0.04	0.85	0.19	0.90
	2	4.93 ±0.27	4.31 ±0.35	4.91 ±0.28	5.02 ±0.33						
Info Quantity[2]	1	4.93 ±0.34	4.84 ±0.29	4.83 ±0.31	4.81 ±0.31	1.33	0.27	0.17	0.68	1.20	0.31
	2	5.01 ±0.33	4.54 ±0.27	5.11 ±0.35	4.87 ±0.32						
Info Quality[2]	1	4.81 ±0.31	4.53 ±0.30	4.70 ±0.33	4.45 ±0.29	0.91	0.44	1.65	0.20	0.26	0.85
	2	4.81 ±0.31	4.76 ±0.29	4.84 ±0.31	4.71 ±0.33						

[1]Lower numbers are better; [2]Higher numbers are better

Three of the six post-trial questionnaire questions were significant for the round main effect; however, no question had a significant main effect for visual condition, or the visual condition by round interaction. The Likert scale for all six questions went from zero to six with zero being the most negative answer, three being neutral, and six being the most positive answer.

The three post-trial questions with significant main effect for round were, ease of finding existing items ($F(1, 234) = 6.320$, $p = 0.01$), responding to neutral UVs ($F(1, 234) = 9.392$, $p < 0.01$), and responding to emerging items ($F(1, 234) = 13.366$, $p < 0.001$). These three subcomponents had the same between round improvement characteristics as many of the NASA-TLX and 10D SART results (Figure 56). The similarities were that the non-GVA condition was the best in round one, did not improve much if any between rounds. However, the GVA related condition did improve, and consequently the non-GVA condition was the worse in round two. On average for the second round the non-GVA condition scored worse by 7.7 ±15.8% than the NE, HC, and Full-GVA conditions. The GVA related conditions, on average, improved by 14.5 ±3.1% between rounds.



	non-GVA	NE	HC	Full-GVA
Ex. R1	3.852	3.835	3.720	3.766
Ex. R2	3.959	4.185	4.180	4.162
Ne. R1	3.926	3.682	3.830	3.921
Ne. R2	4.082	4.164	4.207	4.513
Em. R1	3.690	3.354	3.152	3.425
Em. R2	3.551	4.057	3.845	4.024
Avg R1	3.823	3.624	3.567	3.704
Avg R2	3.864	4.135	4.077	4.233

Figure 56: The post-trial questions, ease of finding existing items (Ex), responding to neutral UVs (Ne), responding to emerging items (Em), and average of the three questions (Avg) results depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

Although the post-trial question rating the overall ease of using the visualization was not significant, the results are interesting since they display many of the between round improvement characteristics present in the NASA-TLX, 10D SART, and other post-experiment questionnaire metrics (Figure 57). Only the Full-GVA condition improved between rounds, by 7.8%. This condition was rated as the most difficult to use during round one and was the easiest to use in round two indicating a probable learning curve. The other three conditions scored worse with the non-GVA condition falling 6.6%, the NE condition falling 4.4%, and the HC condition falling 0.8%. Table 19 provides the question results for the other items that were not significant.

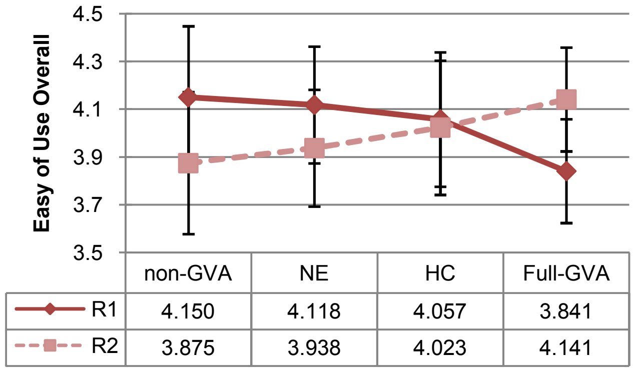


Figure 57: The post-trial question easy of using the visualization overall depicted by visual condition and round (i.e., R1, R2) with 95% confidence intervals. Higher is better.

Table 19: Post-Trial Questionnaire Other Results

Measurement	Round	M ±CI non-GVA	M ±CI NE	M ±CI HC	M ±CI Full-GVA	Visual Condition F(3, 234)	Visual Condition P	Round F(1, 234)	Round p	Interaction F(3, 234)	Interaction p
Understanding	1	4.12 ±0.40	4.15 ±0.34	4.13 ±0.36	4.09 ±0.38	0.33	0.80	1.17	0.28	0.35	0.79
	2	4.29 ±0.38	4.07 ±0.37	4.26 ±0.35	4.14 ±0.36						
Performance	1	4.25 ±0.30	4.38 ±0.24	4.35 ±0.28	4.30 ±0.22	0.26	0.85	0.71	0.40	0.68	0.57
	2	4.24 ±0.33	4.07 ±0.26	4.29 ±0.30	4.33 ±0.24						

Higher numbers are better

The post-experiment questionnaire was composed of the same questions as the post-trial questionnaire, but required participants to directly compare the visual conditions by ranking them from best (1^{st}) to worst (4^{th}) on each question. There were three questions that had a significant effect for the visual condition.

Question one ranked preferences according to how easy each condition was at finding existing information items and the results were significant ($Q(3) = 17.963$, $p < 0.001$) (Figure 58). The NE and HC conditions were significantly different from the non-GVA condition (i.e., differences were larger than the critical difference of 0.85).

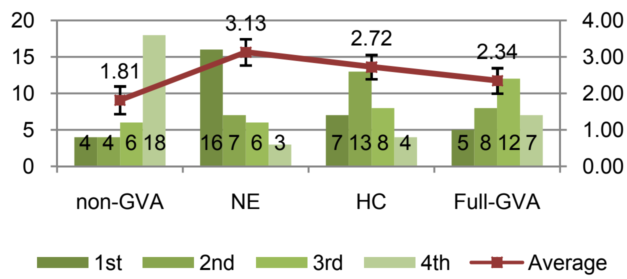


Figure 58: The count of each visual condition's rankings for the post-experiment questionnaire question easiest at finding existing information items on the map (Question 1).

Question two ranked the conditions according to how easy each condition was at identifying when the neutral UV needed to be stopped. None of the rankings were significant. The NE condition was ranked the best (1^{st}) and the worst (4^{th}) almost the same number of times (14 versus 12) (Figure 59).

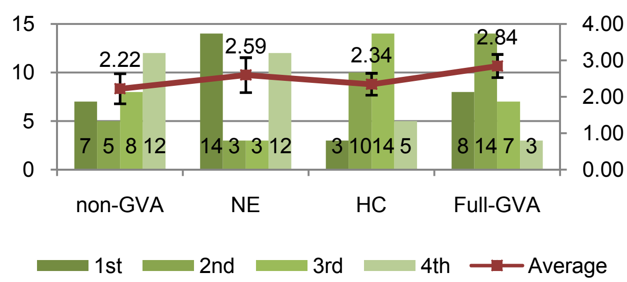


Figure 59: The count of each visual condition's rankings for the post-experiment questionnaire question easiest at identifying when the neutral UV needed to be stopped (Question 2).

Question three ranked according to how easy each condition was at noticing and responding to newly added information items, and the results were significant ($Q(3) = 20.250$, $p < 0.001$) (Figure 60). The NE and HC conditions were significantly different from the non-GVA condition.

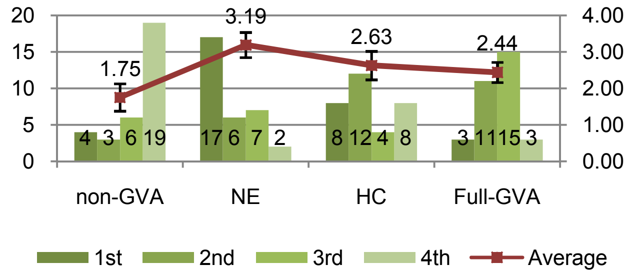


Figure 60: The count of each visual condition's rankings for the post-experiment questionnaire question easiest at noticing and responding to newly added information items (Question 3).

Question four ranked the conditions based on the best at assisting your understanding of the response. None of the rankings were significant (Figure 61). The NE condition, on average was ranked first, the Full-GVA condition ranked second with the HC condition being ranked a close third, and the non-GVA being ranked last.

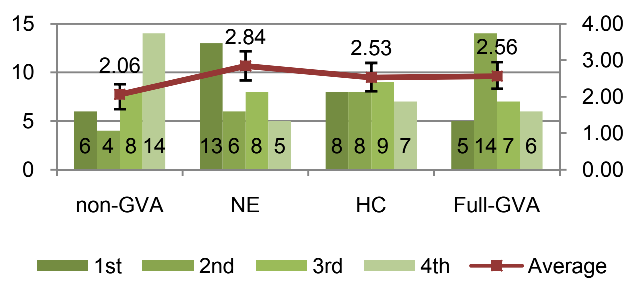


Figure 61: The count of each visual condition's rankings for the post-experiment questionnaire question best at assisting your understanding of the response (Question 4).

Question five ranked according to the best at assisting you in performing your tasks and the rankings were significant ($Q(3) = 9.038$, $p = 0.03$). The NE was significantly different from the non-GVA condition (i.e., difference was larger than the critical difference of 0.85) (Figure 62). The NE condition was first, the Full-GVA condition was a close second, followed by the HC and non-GVA conditions.

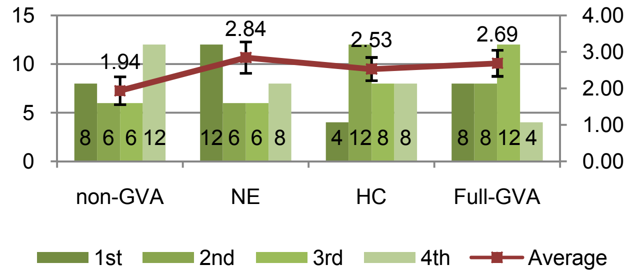


Figure 62: The count of each visual condition's rankings for the post-experiment questionnaire question best at assisting you in performing your tasks (Question 5).

Question six provided the rankings for best overall condition. None of the rankings were significant (Figure 63). The NE condition, on average was ranked first, the Full-GVA condition ranked a close second, the HC condition was third, and the non-GVA being ranked last.

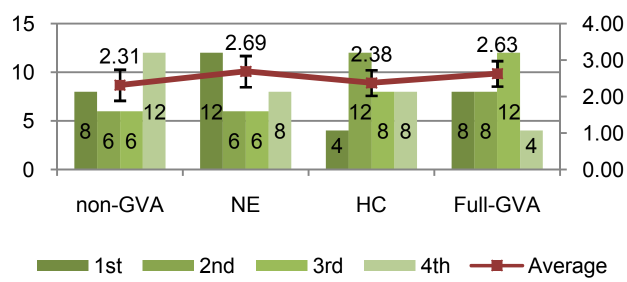


Figure 63: The count of each visual condition's rankings for the post-experiment questionnaire question best overall (Question 6).

Across all questions the visual condition rankings were as follows: NE, Full-GVA, HC, and the non-GVA (Figure 64). The participants ranked the non-GVA condition fourth the most frequently (91) and the Full-GVA condition fourth the least frequently (27).

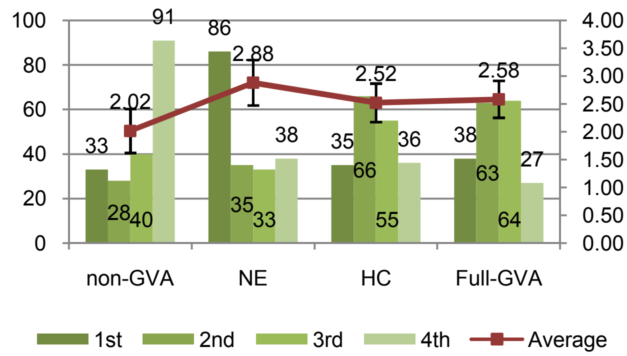


Figure 64: The post-experiment questionnaire total number of times each visual condition was ranked each rank and the average rank on a scale from 1 (worst) to 4 (best).

Discussion

The experimental hypothesis predicted that the Full-GVA condition would be quantitatively preferred over the other three GVA related conditions; however, it narrowly lost to the NE condition. This result, however, was not surprising because several of the post-experiment questions were biased towards parts of the GVA algorithm. For example, the third question, ease of noticing and responding to newly added information items, favored the NE condition, as this condition was focused solely on highlighting novel and emerging information items, a subcomponent of the full GVA algorithm. The two conditions that did not highlight novel and emerging information items (i.e., non-GVA and HC-Only) subsequently scored the worst, as expected. The first question, ease of finding existing information items on the map, was biased towards the HC-only condition, as this condition focuses exclusively on highlighting historically and currently relevant information items (i.e., existing items). The HC condition scored its highest ranking on this question; however, it did lose to the NE condition, which was unexpected. It was expected that the NE condition would score similar to the non-GVA condition (which scored last or fourth) as both did not highlight historically and currently relevant information items. The NE condition's high ranking on this question is a possible indication that this question did not effectively communicate its intent to focus solely on already existing items and not emerging items. Another possibility is that, by being the first question, the result was biased towards the participant's overall favorite, the NE condition. Overall, the GVA related conditions clearly ranked fourth less frequently than the non-GVA condition, which concurs with pervious results that only compared the non-GVA condition to Full-GVA condition (Humphrey & Adams, 2009c).

The second experimental hypothesis section predicted that the non-GVA condition would have higher workload, worse situational awareness, and slower performance times than at least one of the GVA conditions. This hypothesis section was accurate with one caveat: it was only correct during the *second* round. For all three objective workload measures (i.e., Number of Hovers, Percentage Hovering, and Unique Hovers) the non-GVA condition required the most interaction in both rounds. During the second round, these three metrics depicted approximately the same workload for the three GVA related conditions and the separation between their workload and the non-GVA condition was greater (i.e., the non-GVA condition improved less between rounds). The NASA-TLX results for the first round depicted the non-GVA condition as requiring the least workload. However, during the second round the NASA-TLX results complimented the pattern observed in the objective workload measures in that the non-GVA condition improved slightly between rounds, while the GVA conditions improved such that they were each better than the non-GVA condition. The MRQ results were inconclusive, which is the same result as was seen in experiment 1.

The situational awareness results generally followed the same pattern as the NASA-TLX results in that the non-GVA condition provided the best SA in the first round, but was the worst in the second round. However, the Concentration subcomponent results were counter to this pattern. The Concentration subcomponent asked the participants the question “to what degree was one's thoughts brought to bear on the situation”, which may have caused many participants to think about their workload more than their SA. A Pearson correlation coefficient correlating overall workload and Concentration found a significant correlation ($r = 0.362$, $n = 245$, $p < 0.0001$). The possibility exists that the participants may have actually thought that they were choosing a better value for Concentration by choosing a lower value (as they did for workload related questions), but for the 10D SART higher scores are better. Although a few additional 10D SART components were significant, as compared the first evaluation, the overall 10D SART result was again not significant. The between round improvement for the GVA related conditions did, however, follow the same pattern seen in the other metrics for this evaluation.

The prediction that the non-GVA condition would have slower performance times was true for both rounds with respect to the Stop Neutral Time metric. The other performance related objective metrics were inconclusive. However, the post-trial questions related to the ease of performing individual subtasks showed significant improvement between rounds for the GVA related conditions.

Limitations

The main limitation of the GVA algorithms evaluations was that the participants did not face consequences for poor performance. In hindsight, their should have been a consequence when the hazards and neutral UAVs were not correctly responded to within a certain time period. For example a hazard when not responded to could have either expanded its effect radius or caused more victims to appear. This feedback would have provided the participant a means of understanding their performance and may have resulted in more significant subjective metrics related to perferences, workload, and situational awareness.

Conclusion

The GVA algorithm was evaluated in a directable CBRNE visualization for two User Levels and by two different experimental designs (i.e., within and between-subjects). The First Evaluation (i.e., between-subjects design) focused on the overall effectiveness of the GVA algorithm compared to a traditional visualization. That evaluation found that across two User Levels, the GVA algorithm generally lowered workload, improved situational awareness, improved task performance, and was quantitatively preferred.

The Second Evaluation (i.e., within-subjects design) focused on the contributions of the two GVA algorithm information classes: the novel and emerging and the historically and currently relevant. The Second Evaluation results further corroborate the First Evaluation findings that the GVA algorithm can lower workload, improve situational awareness, improve performance, and be quantitatively preferred for directable visualizations.

Another finding that was corroborated across evaluations is that the MRQ questionnaire returned inconclusive results. The MRQ may not have the statistical power to find differences between conditions for these types of experiments, as compared to the NASA-TLX.

The most consistent finding in the Second Evaluation was that the GVA related conditions improved substantially between rounds as compared to the non-GVA condition. Furthermore, the GVA related conditions were generally initially worse than the non-GVA condition. As speculated during the First Evaluation, the participants were likely more familiar with the non-GVA condition, as it is the most similar to online digital maps (e.g., Bing Maps, Google Maps) and consequently required less learning or training to use. However, in nearly all cases, the non-GVA condition improved little or not at all between rounds; whereas, the GVA related conditions improved to the point that the non-GVA condition was, in nearly all cases, the *worst* in the second round. The participants were able to learn enough about the GVA elements in the first round to take advantage of them, thereby improving their experience, in the second round. The corollary is that the GVA algorithm requires some learning before its benefits are recognized. This experiment did not incorporate enough rounds to determine the full potential improvement for the GVA algorithm due to training, which is left as future work.

Although in the Second Evaluation's second round the Full-GVA condition was not always the best, it was usually second out of four. Furthermore, the Full-GVA condition had the least number of fourth place rankings. One of the two partial GVA conditions often performed better than the Full-GVA condition, but this was expected since some metrics focus on task features attuned to one of the partial GVA conditions (e.g., a task involving only an emerging information item). Rarely for the same metric did both the partial GVA conditions do better than the Full-GVA condition. Usually one partial GVA condition did better and one did worse than the Full-GVA condition. This finding suggests that the two partial GVA conditions (i.e., information classes) should be combined through competition and not cooperation in the full GVA algorithm. However, it is left for future work to directly test the competition verses cooperation of the GVA algorithm's information classes.

Although both evaluation results are based on the CBRNE response system, the findings that the Full-GVA condition was an improvement should generalize to other directable visualizations. The OC User Level experiment (i.e., First evaluation, experiment 2) provides support for generalizing these results beyond the CBRNE and UV domains, since the tasks did not directly incorporate UVs, but rather focused solely on interaction with information items. These findings may also be applicable to visualizations beyond the directable type, such as map-based interactive visualizations. For example, if an interactive visualization has a dynamic search feature that allows the users to query for new and different information (e.g., Google maps) and these results are often unpredictable, then this visualization has similar characteristics as a directable visualization. However, proof that the GVA algorithm is applicable to these types of interactive visualization is left for future work.

Contributions

The contributions of this chapter are the results of two user evaluations that demonstrate that the General Visualization Abstraction (GVA) algorithm, by performing information abstraction (i.e., selection and grouping) and determining how information items should be presented (i.e., size), does lower workload, improve situational awareness, and improve task performance. The implication to directable visualizations from these results is that after some user learning, the GVA algorithm's information abstraction and presentation approach is possible and advantageous and these results hold for than one human-robot interaction type interface: operator/supervisor (i.e., US User Level) and abstraction supervisor (i.e., OC User Level).

CHAPTER VIII

DIARE CONCEPT EVALUATION AND RESULTS

The DIARE concept's purpose is to facilitate information sharing between users or across time. The DIARE concept accomplishes its purpose by providing the means to capture a moment in time as a DIARE object, to share this object, and to search for existing DIARE objects. The DIARE concept, unlike the GVA algorithm, does not have independent subcomponents or any straightforward baseline, meaning that either the DIARE concept is present in its entirety, thereby providing sharing, or it is not present and the interface provides no inherent sharing. Therefore, the DIARE concept does not lend itself to condition-based evaluations, as does the GVA algorithm.

This section presents the design and results of an experiment whose purpose was to explore the usability and effectiveness of the DIARE concept for sharing information across time. The evaluation consisted of participants performing various related information sharing tasks and answering a series of in-task understanding questions. Upon completing the tasks the participants answered questions relating to the DIARE concept's perceived usability and effectiveness.

Method

DIARE Concept Hypotheses

The DIARE concept ***hypothesis*** *is that it is useful and easy to understand by the participants.* If the hypothesis is true, then the experiment will have assisted with validating that the DIARE concept is a viable and easy means of sharing information, which is one of the contributions of this thesis.

Participants

Twenty-six participants completed the evaluation and were compensated $25 USD. All participants were at least 18 years of age. Participants were screened for five requirements: at least a high school education, computer competency, English competency, no experience with the experimental maps, and no prior exposure to the interface. All participants had normal or corrected-to-normal vision including not being color-blind and were not required to have domain specific knowledge (i.e., CBRNE incident response knowledge).

Evaluation Apparatus

The interface program was comprised of three sections, as shown in Figure 36 in Chapter VI: the left map display section, the bottom DIARE concept section, and the right robot task information display. The participants learned to interact with the map components during the system overview, while performing remote operator tasks from the second GVA evaluation, and DIARE training trial. A limited number of map items or information item types representing hazards (e.g., explosive), hazard or sensor readings, eye witness reports, vehicles, etc. were displayed on the map. The information item designs were based on existing graphical standards (e.g., U.S. placard for hazardous materials). The participants were familiar with the information items before the DIARE training trial from their extensive use of the interface during the trials for the second GVA evaluation (Chapter VII).

Procedure and Data Collection

This experiment followed directly from the second GVA evaluation. The participants completed the GVA evaluation prior to commencing this experiment. The GVA evaluation provided participants with training on how the interface map and items on the map functioned before completing the DIARE experiment. This extensive training helped ensure that the participants were familiar with all aspects of the interface except the DIARE and therefore created separation of the usability and effectiveness of the DIARE concept from the other interface elements. Each participant performed one DIARE training trial, and then one DIARE experimental trial. The training trial was a simpler version of the experimental trial. All trials were based on a realistic CBRNE scenario involving a train derailment precipitated incident (see Chapter III). The training trial and the experimental trial employed a unique incident with a unique aerial map that were both different from each other and different from prior evaluation trials in order to minimize cross trial learning effects. The training trial incorporated more than eight hours of recorded events with four initial DIARE objects. The experimental trial incorporated eighteen hours of recorded events with eight initial DIARE objects. The DIARE training and experimental trials lasted approximately five minutes each.

During both the training and the experimental trials, the participants interacted with the interface from the perspective of someone who had recently arrived on the scene in order to relieve others (i.e., part of a new work shift). Their primary responsibility was to explore and understand what had happened during the incident by interacting with the DIARE. The trial structures were the same. The first step of the DIARE training trial and experimental trial was to use the DIARE to explore and understand what had occurred. After approximately one minute into the experimental trial, they were asked five in-task questions about what had happened. There were two recorded components for the in-task questions: was the answer from memory (i.e., did they answer without interacting or scanning the interface) and was the answer correct. Prior to beginning the experimental trial, the participants were told that they were not required to memorize the incident and they could use the DIARE to answer the in-task questions. After the in-task questions, the participants were instructed to create one DIARE object to facilitate the information sharing for a particular purpose.

After the experimental trial, participants completed a final questionnaire. The final questionnaire was comprised of seven quantitative questions and three qualitative questions designed to assess the usability and effectiveness of the DIARE concept.

Results

All reported statistics are independent one-sample two-tailed *t*-tests with the null hypothesis being that the population mean is equal to 4 or neutral unless otherwise stated. The 95% confidence interval (CI), median, and Hedges' g (ES(g)) (1981) effect size measures are also reported.

In-Task Question Metrics

The participants answered five questions that were designed to elicit the participants' understanding of the past event response activities. Each question had two related metrics as shown in Figure 65: response type (i.e., did the participant recall the information from memory or did they use the DIARE to ascertain the answer), and response validity (i.e., was their answer correct or incorrect). Regarding response type, though memorization was not required of the participants, whether or not they were able to answer a question from memory indicated whether the DIARE concept facilitated their ability to assimilate the knowledge.

Figure 65 depicts the results for each in-task question. Question one (Q1) required participants to list the major hazards in order of occurrence. Half (50%) of the participants answered this question from memory, with 96.2% of all participants answering correctly. The second question (Q2) asked the participants to provide the details of a particular hazard. All participant answers were correct, with only 19.2% answering from memory. The third question (Q3) focused on the participant's ability to identify a time related pattern (e.g., which direction the hazards were spreading). 65.4%

of the participants answered from memory and 96.2% provided correct answers. Question four (Q4) required participants to provide an answer related to information presented at the beginning of the incidents (e.g., was the first 911 call reported related to the ensuing hazards). 38.5% of the answers were from memory, with 96.2% correct answers. The final question (Q5) required the participants to assess a particular feature across time (e.g., did the UVs spend the majority of the time surveying). All participants provided correct answers, with 46.2% of the participants answering from memory. Across all tasks, the participants answered the questions from memory 43.8% of the time and their answers were correct 97.7% of the time.

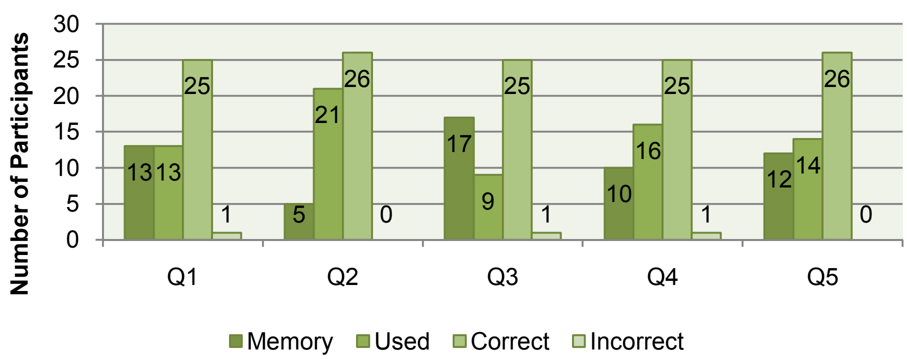


Figure 65: The In-Task Question related metrics depicting the number of participants that answered each question from memory or by using the DIARE (Used) and gave a correct or incorrect answer.

The Final Questionnaire

The final questionnaire asked the participants seven quantitative questions and three qualitative questions. The seven quantitative questions were rated on a Likert scale from 1, being very negative to 7 being very positive. The Likert scale value 4 represented a neutral rating. The results are provided in Table 20. A statistical analysis found that the results were significant and in favor of positive answers or averages greater than 4.

Table 20: The Final Questionnaire Results

Question	Non-GVA M ±CI	Median	Comparisons t(df = 25, $\mu_0 = 4$)	p	ES(g)
Q1: Locate	5.15 ±0.55	5	4.10	< 0.001	0.61
Q2: Understand Object	4.88 ±0.54	5	3.23	< 0.01	0.38
Q3: Create	6.04 ±0.41	6	9.66	< 0.0001	3.36
Q4: Understand History	5.54 ±0.41	5	7.35	< 0.0001	1.95
Q5: Overall Interaction	5.27 ±0.46	5	5.46	< 0.0001	1.08
Q6: Sharing Utility	5.58 ±0.42	6	7.30	< 0.0001	1.92
Q7: Sharing Effectiveness	5.69 ±0.36	6	9.30	< 0.0001	3.12

[1]Scores can range from 1 (low) to 7 (high), with higher being better

Figure 66 depicts the results of the first question, which required the participants to evaluate the difficulty of locating a visual DIARE object. The result was a median value of 5, or slightly easy, with 62% of the participants answering positively. There were two general strategies used to locate a visual DIARE object: visually scan the DIARE timeline and click on the object, or move the display time to the approximate visual DIARE object time and then scan for and click on the object. The advantage of the second strategy is that visual DIARE objects closest in time to the *display time* are aligned directly below the *display time* location.

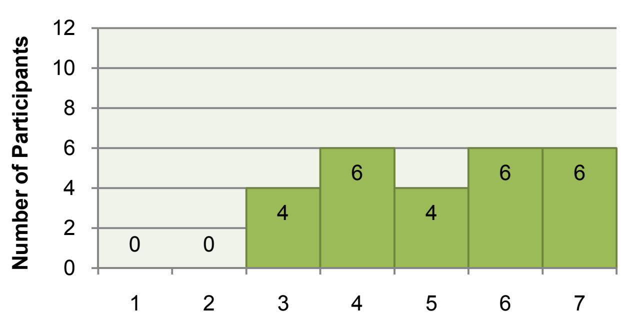


Figure 66: The final question, "How difficult was it to locate a DIARE object?" (Q1) histogram. Likert values, 1: Very Difficult, 4: Neutral, 7: Very Easy.

Figure 67 illustrates the results of question two, which required participants to evaluate the difficulty of understanding the information contained in a DIARE object. The result was a median value of 5, or slightly easy, with 65% of participants answering positively. The information contained in the visual DIARE object was title, start time, tags, and snapshot. Once a DIARE object had been selected, the other general DIARE object information was displayed: capture time, zoom level, map position, and related information items. Due to the DIARE object's complex conceptual nature (i.e., some elements can be visualized easier than others) it was expected that there may be some difficulty in understanding the information, and indeed 27% of the participant answered this question unfavorably. Only 12% of the participants felt that the information was very easy to understand, the lowest number for any question. However, the overall result was favorable and significant, indicating that the DIARE concept was able to present DIARE objects in an understandable manner despite its complex conceptual nature.

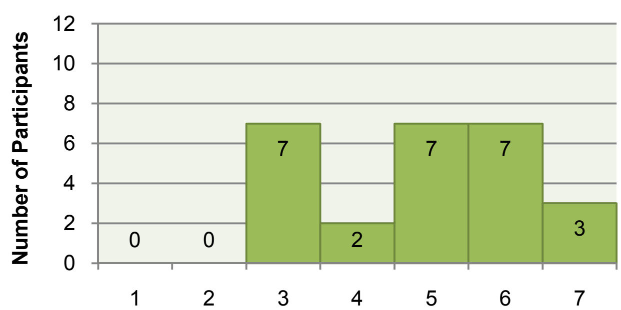


Figure 67: The final question, "How difficult was it to understand the information contained in a DIARE object?" (Q2) histogram. Likert values, 1: Very Difficult, 4: Neutral, 7: Very Easy.

Figure 68 portrays the results of question three that required participants to evaluate the difficulty of creating a new DIARE object. The result was a median value of 6, indicating that creating an object was easy, with 88% of the participants answering positively. The DIARE object was created by first selecting the “create DIARE” button, then completing the fields in the newly displayed panel, and then selecting “finish”. This process was straightforward, as was supported with no negative participant responses and 46% of the participants responding that it was very easy, the best possible answer.

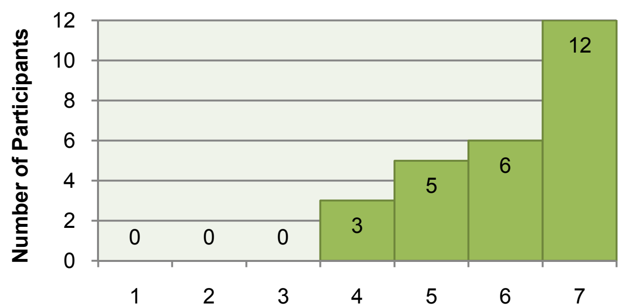


Figure 68: The final question, “How difficult was it to create a new DIARE object?” (Q3) histogram. Likert values, 1: Very Difficult, 4: Neutral, 7: Very Easy.

Figure 69 depicts the results for the fourth question that required participants to evaluate whether they felt they knew what had transpired after using the DIARE concept. The result was a median value of 5, indicating that they somewhat agreed, with 88% positive participant answers. The trial incorporated over 18 hours of incident history with three major hazards and over hundred information items that comprised “what had happened”. Furthermore, no participants had incident management experience and, therefore, it was not surprising that many participants answered cautiously (i.e., value of 5).

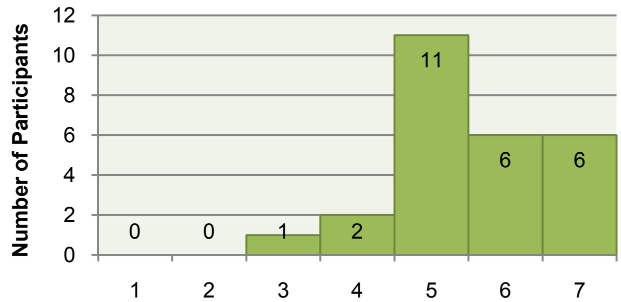


Figure 69: The final question, "After using the DIARE concept, did you feel as though you knew what had happened?" (Q4) histogram. Likert values, 1: Completely Disagree, 4: Neutral, 7: Completely Agree.

Figure 70 illustrates the results of question 5, which required participants to evaluate the overall difficulty of interacting and using the DIARE concept. The result was a median value of 6, or easy, with 73% of the participants answering positively. There are four subcomponents that can be interacted with: the DIARE timeline, incident timeline, and new DIARE object panel. Although the answers were categorically positive, only 15% answered that it was very easy to use, indicating that there is room for improvement.

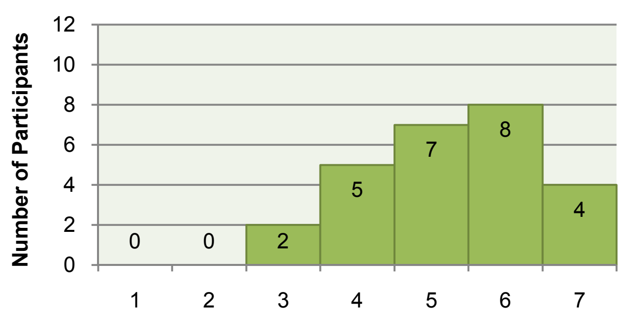


Figure 70: The final question, "How difficult, overall, was it to interact and use the DIARE concept?" (Q5) histogram. Likert values, 1: Very Difficult, 4: Neutral, 7: Very Easy.

Figure 71 portrays the results of question six, which required participants to evaluate their perceived potential utility of the DIARE concept with regard to sharing information. The result was a median value of 6, indicating that it was potentially useful, with 81% of the participants answering positively. Although the participants did not participate in any direct sharing in real-time, they were told in the opening narrative that the DIARE objects at the start of the trial were created by a person on the pervious shift. They were also instructed to create new DIARE objects to assist both themselves in the future (e.g., creating an object to denote when they started their shift), and others in the present (e.g., capturing the discovery of a new hazard).

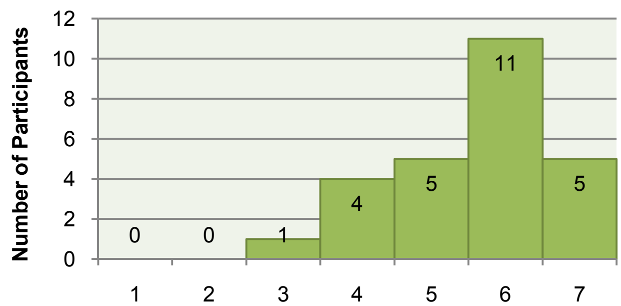


Figure 71: The final question, "How potentially useful do you perceive the DIARE concept to be in regarding to sharing information?" (Q6) histogram. Likert values, 1: Very Useless, 4: Neutral, 7: Very Useful.

Figure 72 depicts the results of the seventh question, which required participants to evaluate their perceived potential effectiveness of the DIARE concept regarding the sharing of information. The result was a median value of 6, indicating that they perceived it to be potentially effective, with 88% answering positively. This question is closely related to question 6, which focused to the utility rather than the effectiveness of sharing information. The responses to question 7 were more positive than the responses to question 6 (Table 20), indicating that although a few participants were unsure whether the DIARE concept would be useful in sharing information, it was determined that if information was shared, it would be effective.

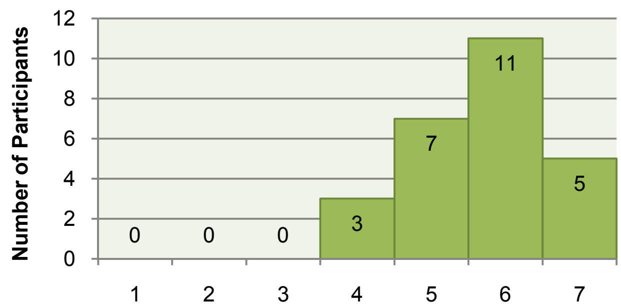


Figure 72: The final question, "How potentially effective do you perceive the DIARE concept to be in regarding to sharing information?" (Q7) histogram. Likert values, 1: Very Ineffective, 4: Neutral, 7: Very Effective.

Limitation

The main limitation of the DIARE concept evaluation was that the participants were unable to share information across users in real-time. This limitation was because the underlining CBRNE interface system did not currently support multiple parallel users. Therefore, the DIARE concept was only evaluated for its ability to sharing information across time.

Discussion

As hypothesized, the DIARE concept was statistically found to be useful and easy to understand by the participants. Across all seven final questions the participants statistically answered positively and in support of the DIARE concept's ease of use, ability to be understood, and information sharing. The In-Task question metrics support these final question results in a number of ways. First, although the participants were not required to memorize information, many participants nevertheless did, with 43.8 ±14.8%

of answers being recalled from memory. The memory recall percentage for the in-task questions was higher than anticipated, especially for question one (50%) and question three (65.4%), both of which asked questions relating to information across time. Secondly, the participants answered more than 98% off all questions correctly, indicating that their DIARE assessed understanding was accurate.

The DIARE concept aspect that was least favorable (although still statistically positive) was the participants' understanding of the information contained in a DIARE object. The DIARE object is the most conceptually complex component in the DIARE concept. The visual DIARE object, incident timeline, and create new DIARE object panel are all similar to existing (and probably familiar) examples.

The visual DIARE object's predominate feature is the snapshot, which is analogous to DVD/Blue-ray chapter indexes; however, the response when choosing a visual DIARE object is different. When choosing a movie chapter by chapter index the movie "jumps" to that scene and begins playing. When clicking on a visual DIARE object, although the interface map jumps to the DIARE object's start time, more than just the *display time* changes. Other changes include the visual DIARE object becoming highlighted, information items related to the DIARE object becoming highlighted, non-related information items either reducing in size or disappearing (if the item did not exist at that time), and the map's scale and viewable window are recentered. Furthermore, unlike the movie analogy, many component features stay the same: the location of interface components, aerial map, most of the visual DIARE objects locations in the DIARE timeline, and many information items that were present on the map before the jump.

There was some indication, based on participant observation, that the “jump” analogy (discussed in the previous paragraph) is not ideal for the DIARE concept. Instead, a transitional effect, or a series of animated actions, could have been presented to visually and cognitively assist the participants with identifying elements that changed. The current DIARE concept employing the “jump” analogy is classifiable as having partially revealed to fully revealed effects according to Reeves et al.’s taxonomy (Reeves, Benford, O'Malley, & Fraser, 2005). If a future DIARE concept version instead employed a transitional effect it would become an amplified visualization (Reeves et al., 2005), which may assist with fully understanding the information contained in a DIARE object.

Although these DIARE concept results are based on the CBRNE response system, the positive findings should generalize to other geographic information systems (GIS) management interfaces. Future work will include improving the DIARE concept playback feature and introducing a mechanism to compare two DIARE objects or a DIARE object to another moment in time. Furthermore, an additional study is required to ascertain the DIARE concept’s ability to share information across User Levels in real-time.

Contributions

This chapter’s contribution is the results of a user evaluation that provided evidence that the Decision Information Abstracted to a Relevant Encapsulation (DIARE) concept provides potential users with a useful and easy to understand mechanism to rapidly ascertain what had happened during an emergency incident (i.e., information sharing across time). After using the DIARE concept, almost half of the participants were able to answer in-task questions regarding incident understanding from memory, even though they were not required nor told to do so. The implication to emergency incident geographical map-based systems is that the DIARE concept provides a solution to the information sharing problem.

CHAPTER IX

CONCLUSION

This dissertation seeks to inform the development of a system of human-robot interfaces where each interface permits information sharing and visualization at the appropriate abstraction level, given users' responsibilities and position in a hierarchical command structure. The contributions of this dissertation are as follows.

The first contribution is the modifications to the Cognitive Task Analysis (CTA) techniques, the Goal-Directed Task Analysis (GDTA) and the Cognitive Work Analysis (CWA), that were found to be necessary to support the CBRNE response system's broad domain scope and its human-based nature, which are not representative of traditional domains analyzed using the GDTA and CWA. Specifically, this dissertation presented the first applications of these modified techniques to a system with a broad scope in which humans were considered to be system components, rather than system users. These modifications (e.g., the expanded goal-decision-SA structure, the use of statecharts) should permit the application of the GDTA and CWA to other broad, complex domains and to domains in which humans represent integral system components.

The second contribution is the actual CTA results that were gathered to gain an understanding of the CBRNE domain and its complexities in order to provide insight for the design and development of CBRNE related robotics projects (e.g., HRI, physical robot requirements). The results provided evidence that the two methods, when performed together, provide synergy and a more complete analysis than either method can provide in isolation (e.g., by identifying different response concerns due to their different perspectives).

The CBRNE CTAs identified a very large number of individual human contributors due to the fact that the CBRNE domain has responders from the local, county, state, and federal governments; the military; and private sector. Given the large number of human contributors, it was impractical to develop individual interfaces for each one. This fact led to the third contribution, the formation of the Emergency Response Human-Robotic Interaction (HRI) User Level definitions that abstracted the individual users into ten types, or levels. These ten User Level definitions represent the individual human contributors in a manner similar to the command hierarchy and permits the grouping of users with similar responsibilities. The User Levels are not specific to the CBRNE domain, but are applicable to most first response domains. Furthermore, the User Levels facilitated the design of interfaces for large and diverse human organizations.

The fourth contribution is the development of the Cognitive Information Flow Analysis (CIFA) technique that was designed to address some of the CTA methods' issues (e.g., providing parallelism and goal questions) and to combine their results to facilitate design and development of the system of human-robot interfaces. The CIFA addresses these issues and provides a new perspective by focusing on the path and transformation of information through the system and its User Levels. This new perspective is its greatest contribution.

The primary contribution of this dissertation is the development and evaluation of two visualization techniques: the General Visualization Abstraction (GVA) algorithm and the Decision Information Abstracted to a Relevant Encapsulation (DIARE) concept, which together provide integration, abstraction, and sharing of the information generated by the response system, including remotely deployed robots. Existing solutions for abstracting information for presentation on an interface are not robust or flexible enough for the complicated CBRNE domain employing a directable visualization, thus the GVA algorithm was developed. The identification and definition of directable visualizations itself is a contribution as its distinguishes visualization like those to be used in CBRNE domain from other classes of visualizations. The GVA algorithm is a contribution that provides a novel method for abstracting information in an intelligent way by supporting unanticipated situations and novel information items, reducing visual clutter, and making important information more salient. The user evaluations provided evidence that the GVA algorithm lowers workload, increases situational awareness, and improves performance. Furthermore, the evaluations provided some evidence of how the information classes (e.g., historically and currently relevant and novel and emerging) contributed to the overall algorithm.

The development of the DIARE concept was motivated by both the CBRNE analyses and a literature review identifying the need for information sharing across long periods of time (e.g. days) and across the users within the command hierarchy. Sharing across users includes sharing information between users at the same User Level (e.g., UV Specialist), across different work shifts, users in different physical locations, and users at different User Levels who have different interfaces and task focuses. The design of the DIARE concept is a contribution as it provides a novel method to facilitate accessing stored volumes of information so that users can understand prior important events and to share the volumes of information across users.

Lessons Learned

There were a number of lessons learned that are broken into two areas: the domain analysis and the development of the new visualizations. The most important lessons learned from the analysis were that understanding the path of information through the system, the association of users to goals, the decision question related to a goal, the tools used to achieve a goal, and the representation of parallelism and partial ordering of goals were the very important attributes to capture (listed in descending importance). The need to incorporate these attributes led to the modification of the two CTA methods. The CBRNE's broad scope and the representation of humans as system components also contributed to the need for the CTA modifications. These attributes are all present in the CIFA, which also utilizes the User Levels. The CIFA technique was invaluable in defining robot tasks, CBRNE interface design, information abstraction and representation (e.g., information grouping), and designing the visualizations. Without the CIFA those development tasks would have been exceedingly more difficult and the results less robust.

While developing the User Level definitions for the emergency response domain it was discovered that some users interact with the robots differently than the previously defined HRI roles specified. This new HRI role is the abstract supervisor, which exists in very hierarchical organizations, like the CBRNE response system. This role indicates a person who uses abstract robot derived information and then makes decisions that implicitly effect the robots.

The lesson learned, based on the design and evaluation results, of the GVA algorithm is that its approach of evaluating an information items importance based on its association with two information classes, historically and currently relevant and novel and emerging, assists in making important, relevant decision related information more salient. It is also believed that the GVA algorithm may be beneficial to a broader range of visualizations beyond directable visualizations; for example, standard map-based interfaces that display real-time query-based search results.

The lesson learned, based on the evaluation results, for the DIARE concept is that it provides a means for users to rapidly assimilate stored information with good memory recall. The techniques represented in the DIARE concept appear, based on observations, to assist users with developing an internal narrative about historical information. This finding is based on the participants memorizing a large amount of the stored information. When asked about historical information, it appeared as if the participants were remembering their constructed story and then retelling it to answer the questions.

Conclusions

This dissertation presented three evaluations: two for the GVA algorithm and one for the DIARE concept. The evaluations provided some insights into the design of experiments. The MRQ was included at the suggestion of prior paper reviewers and existing literature that suggested that the MRQ better measures subjective workload than the NASA-TLX. However, the MRQ appears to have less statistical power and its results did not form any consistent pattern for the types of evaluations conducted in this dissertation in comparison to the NASA-TLX, which did yield significant and consistent results. The 10D SART was performed to gather situational awareness (SA) results but, like the MRQ, did not yield significant results. The 10D SART may have less statistical power than the 3D SART, which had been used in our prior published evaluations. The hypothesis is that the 10D SART questions were difficult for participants to understand (and, therefore, answer accurately) because in some question instances higher scores were positive (i.e., indicating improved SA), while for other questions higher scores were negative (i.e., indicating a decrease in SA). The design of the evaluations provided insight in that the between-subject evaluations generally yielded more significant performance metrics; whereas, the with-in subject design yielded more significant subjective metrics.

In conclusion, this dissertation is informing the design and development of a system of human-robot interfaces for the CBRNE domain by contributing in two areas: by analyzing the domain and by developing new visualizations. The CBRNE domain was analyzed using the modified CTAs and CIFA to provide a robust and multifaceted understanding for the design and development process. The CIFA and the User Levels were, in particular, of great value for design and development that led directly to ascertaining robotic tasks and informing interface design. The two new visualizations, the GVA algorithm and the DIARE concept, collectively can assist decision-makers using directable visualizations, such as those used in HRI, by offering an effective method of sharing and providing real-time, relevant information.

Future Work

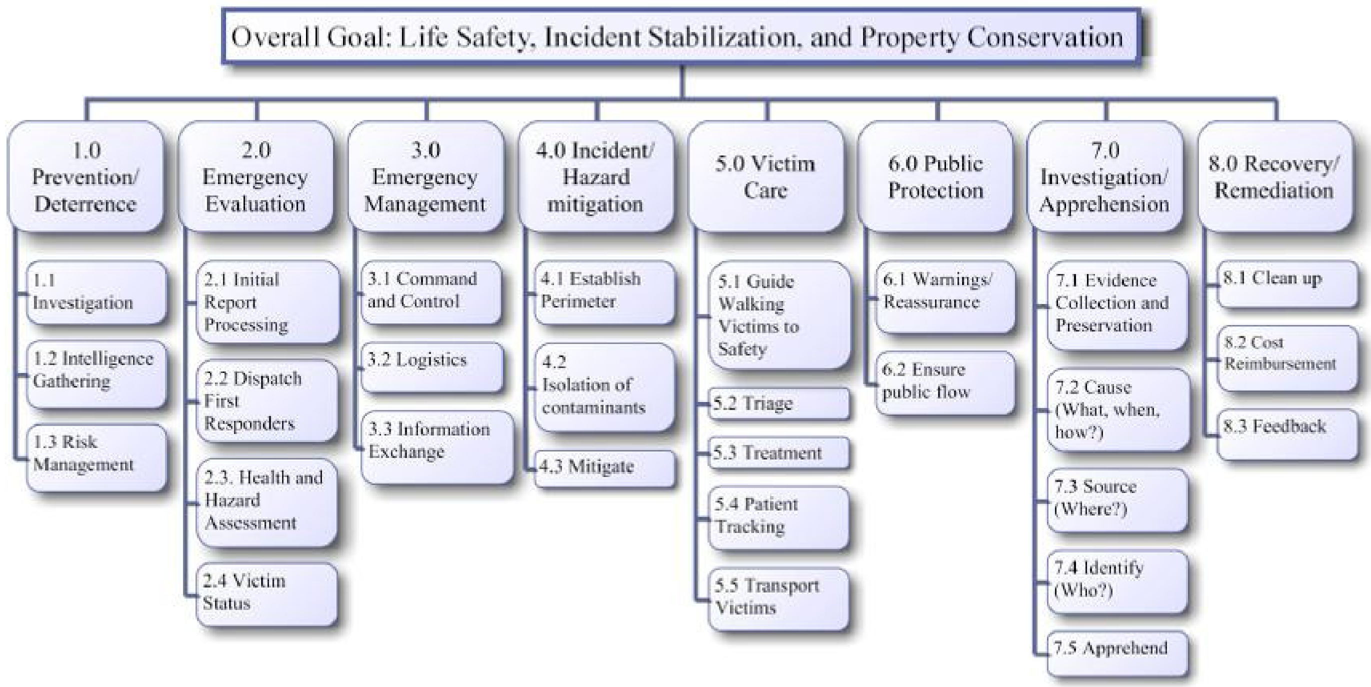
The modified Cognitive Work Analysis, presented in Chapter III, discussed developing a plan regarding the incorporation, training, and failure detection of the proposed CBRNE robotic system. However, the CBRNE robotic system is still in the early stages of development, thus these additional CWA step cannot be taken until a functional system is available. The simulated robots used in this research were ideal and did not suffer failures. A high fidelity simulation and real robotic systems are currently under development.

This dissertation developed interfaces for testing tasks at two different User Levels. Designing and developing interfaces for the other User Levels will be left for future work. The Cognitive Information Flow Analysis (CIFA) technique, presented in Chapter V, was not applied directly to analyzing a system, rather, it was developed based upon the CTA results from Chapter III. Although, it should be possible to perform the CIFA technique without first performing other CTA methods, the proof is left for future work. The CIFA technique was also only performed on an revolutionary or semi-revolutionary system; therefore, proof that it is applicable to evolutionary systems is left for future work.

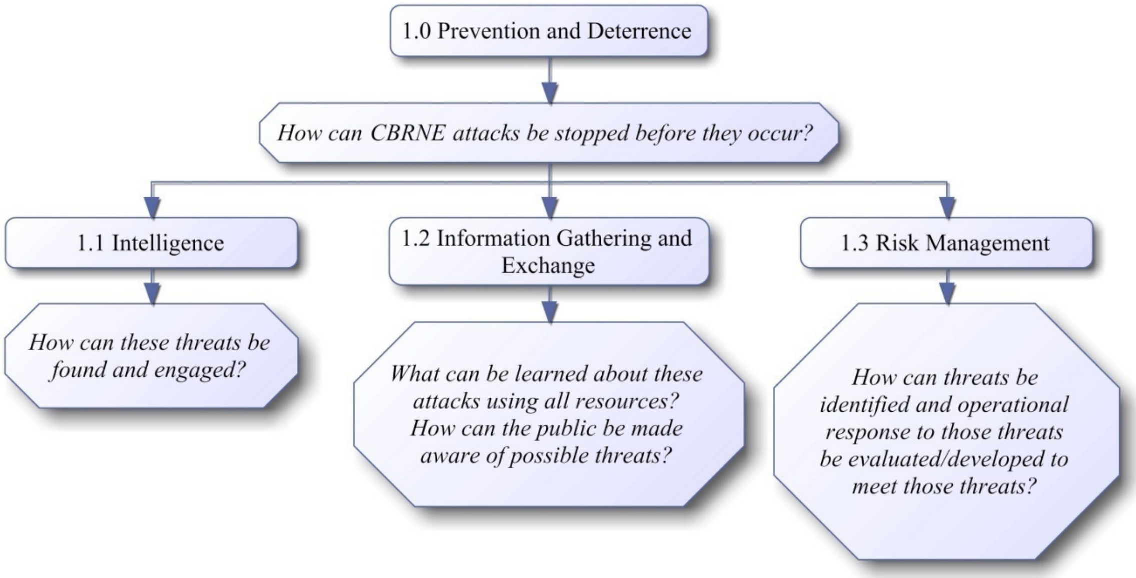
The GVA algorithm was developed for directable visualizations (see Chapter VI), but the evaluation results (see Chapter VII) were based only on the CBRNE domain. The results and findings, however, should be applicable to directable visualizations in general and possibly more broadly applicable to interactive visualizations; however, proof is left for future work. The results demonstrated that the participants improved through time their visualization experience when utilizing the GVA algorithm much more than they did when not employing the algorithm. The evaluations only evaluated the GVA algorithm for two rounds and, therefore, the potential maximum GVA algorithm visualization experience improvement versus a non-GVA visualization is unknown and left for future work.

Although the DIARE concept was only evaluated in the context of the CBRNE response system, the findings should generalize to other geographic information systems (GIS) management interfaces. Proof of its ability to generalize is left for future work. Based on participant feedback and results, future designs of the DIARE should introducing a mechanism to compare two DIARE objects or one DIARE object to another moment in time. Future designs should also employ transitional effects when switching between DIARE objects or two points in time. Furthermore, because the CBRNE system does not currently permit multiple concurrent interfaces to share data, an additional study is required to ascertain the DIARE concept's ability to share information across User Levels in real-time.

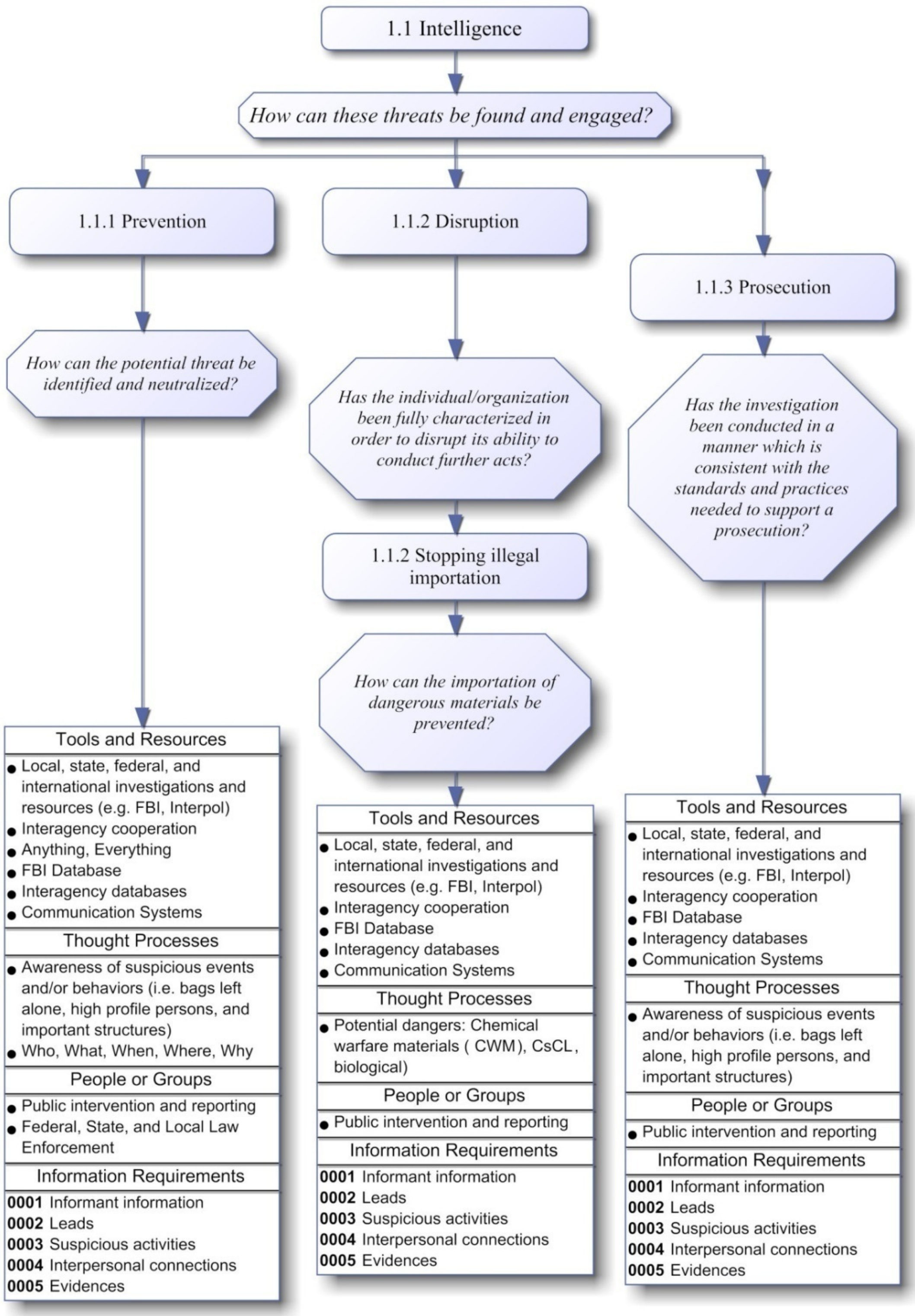
APPENDIX A: THE COMPLETE RESULTS OF THE GDTA.



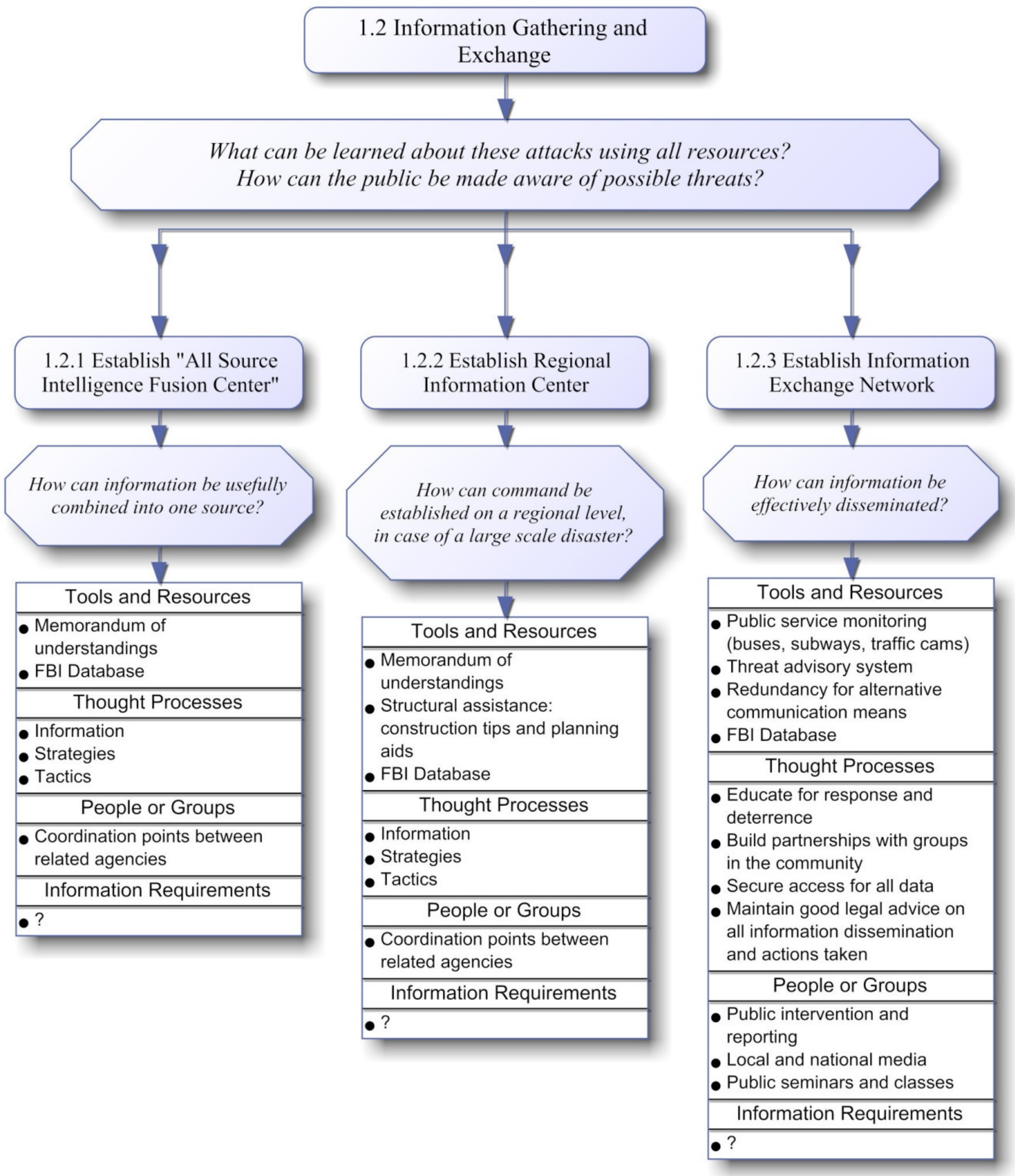
Appendix A.1: The overall GDTA Goal



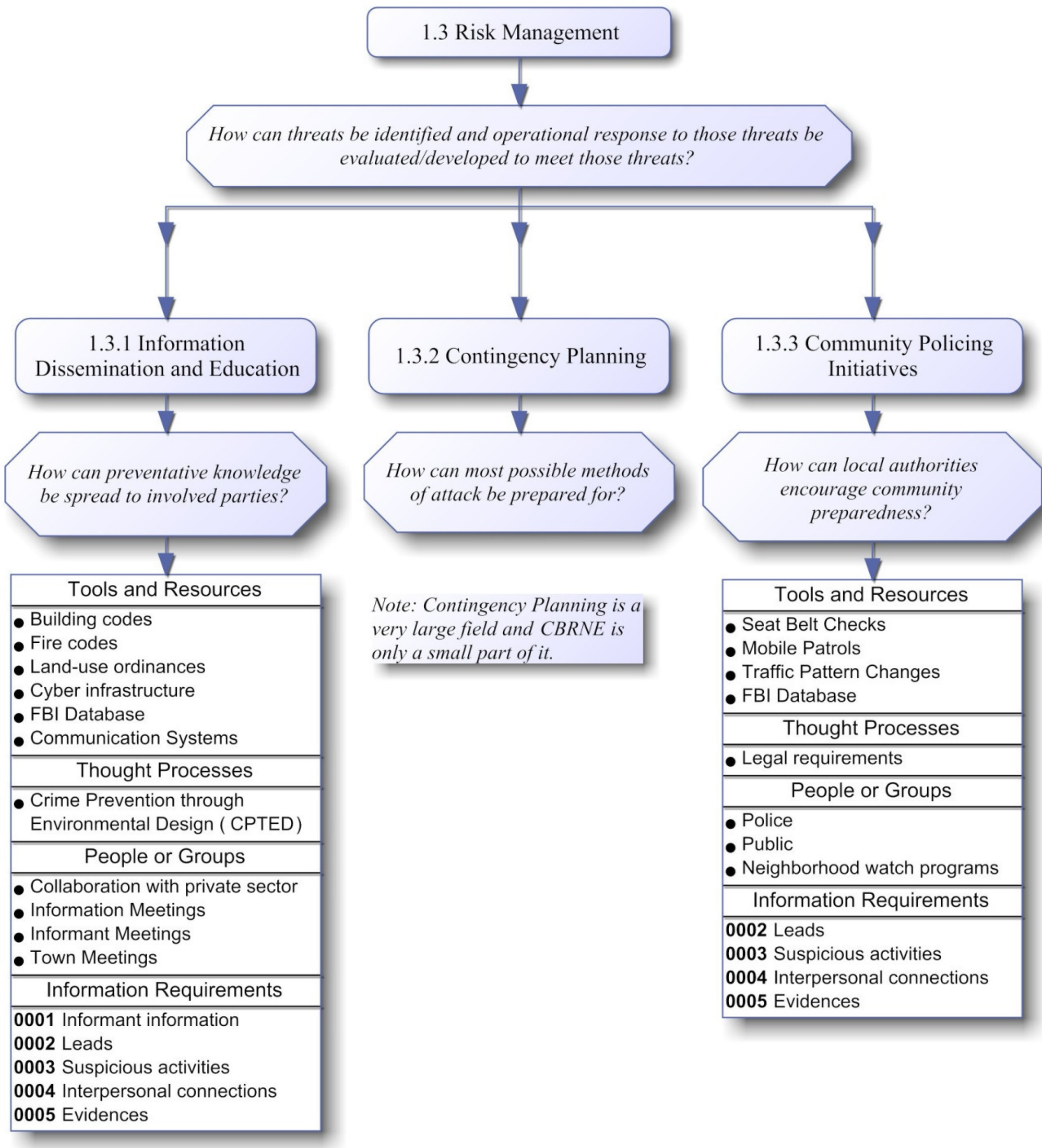
Appendix A.2: GDTA 1.0 Prevention and Deterrence



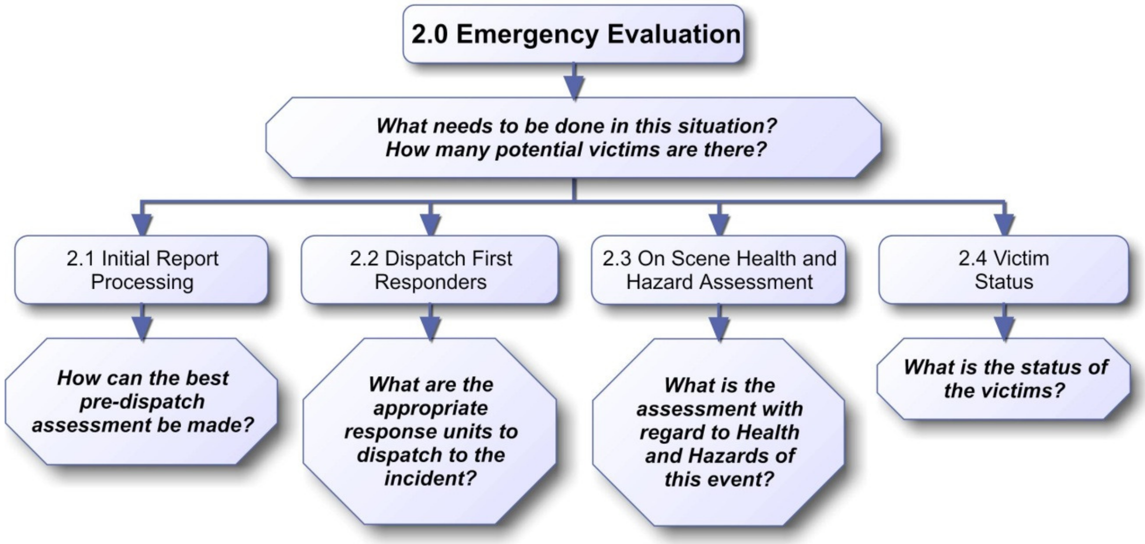
Appendix A.3: GDTA 1.1 Intelligence



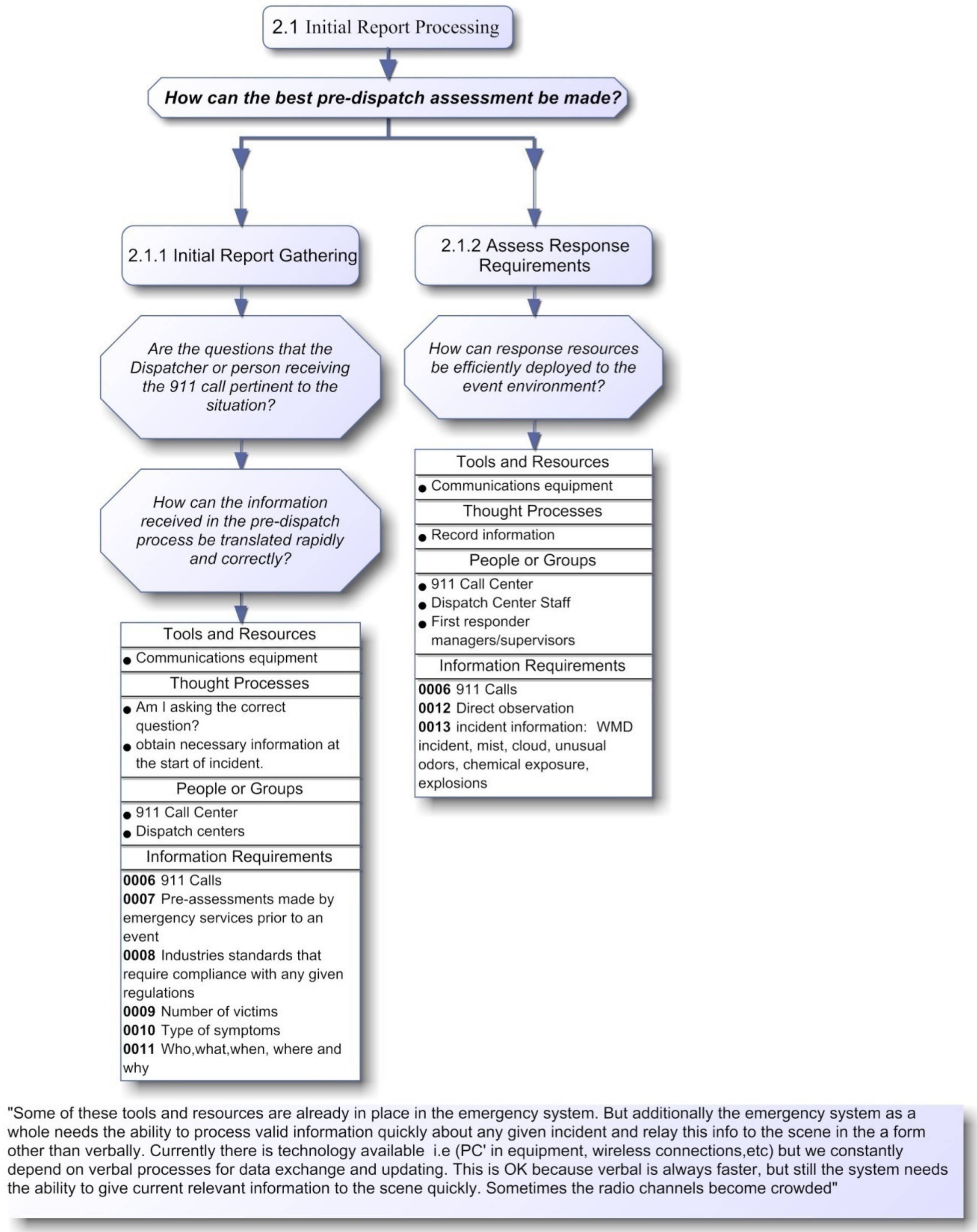
Appendix A.4: GDTA 1.2 Information Gathering and Exchange



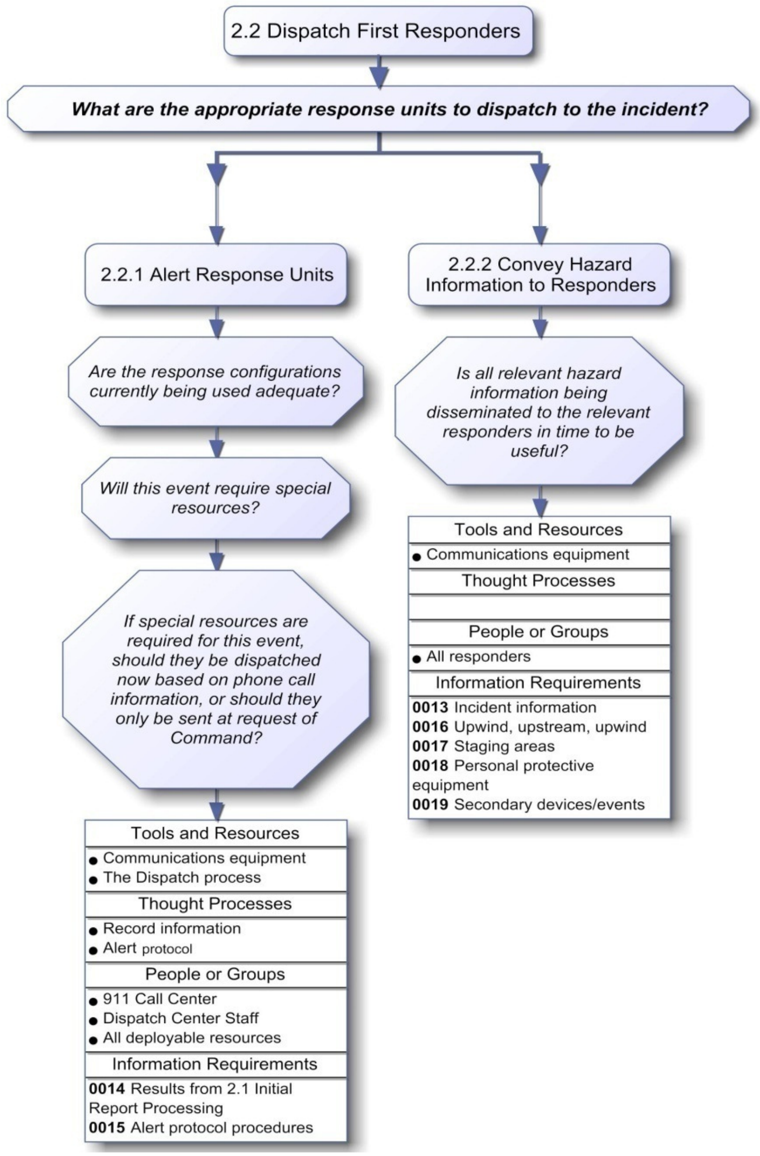
Appendix A.5: GDTA 1.3 Risk Managements



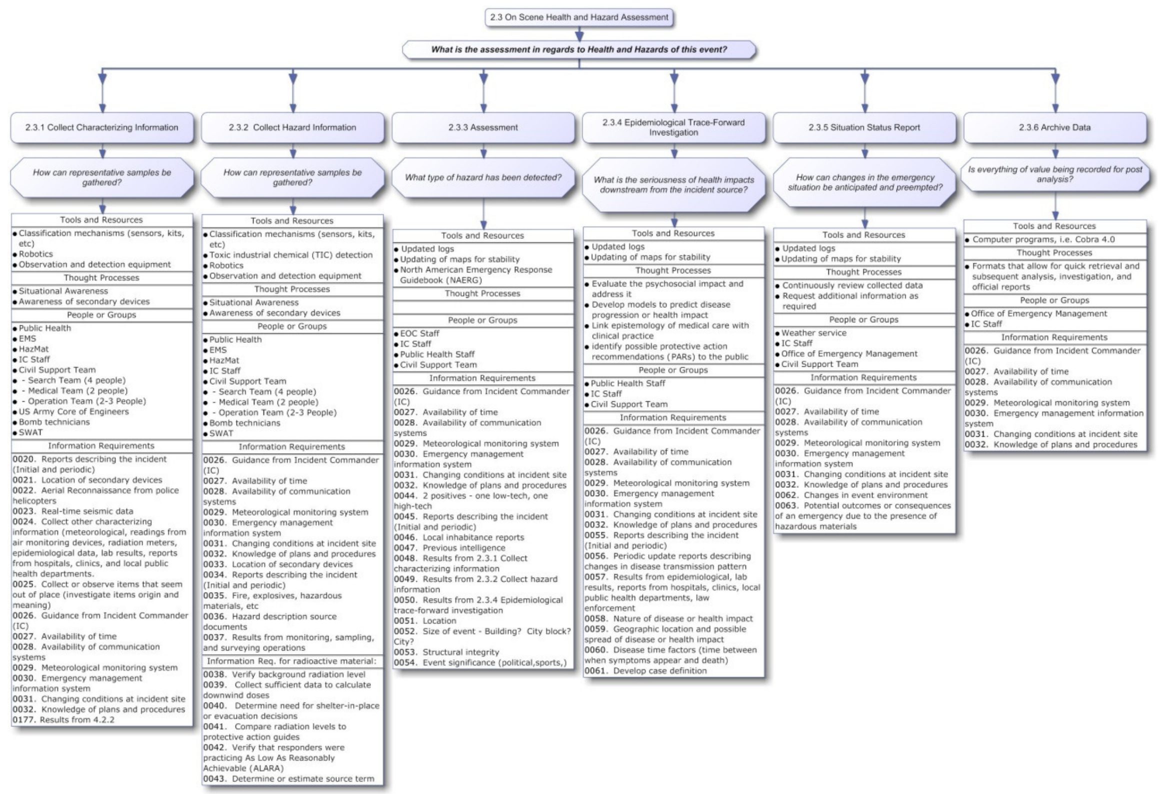
Appendix A.6: GDTA 2.0 Emergency Evaluation



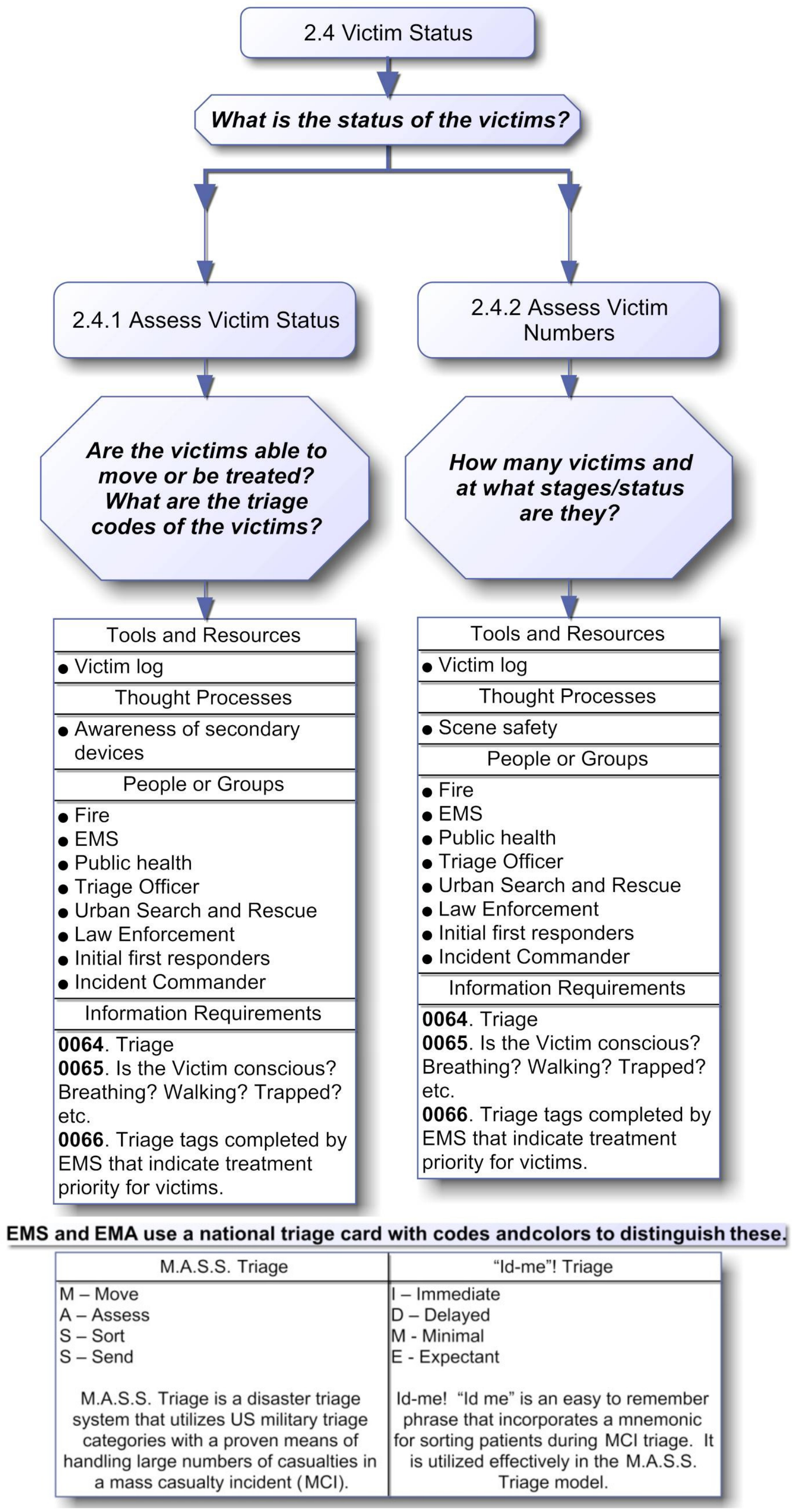
Appendix A.7: GDTA 2.1 Initial Report Processing



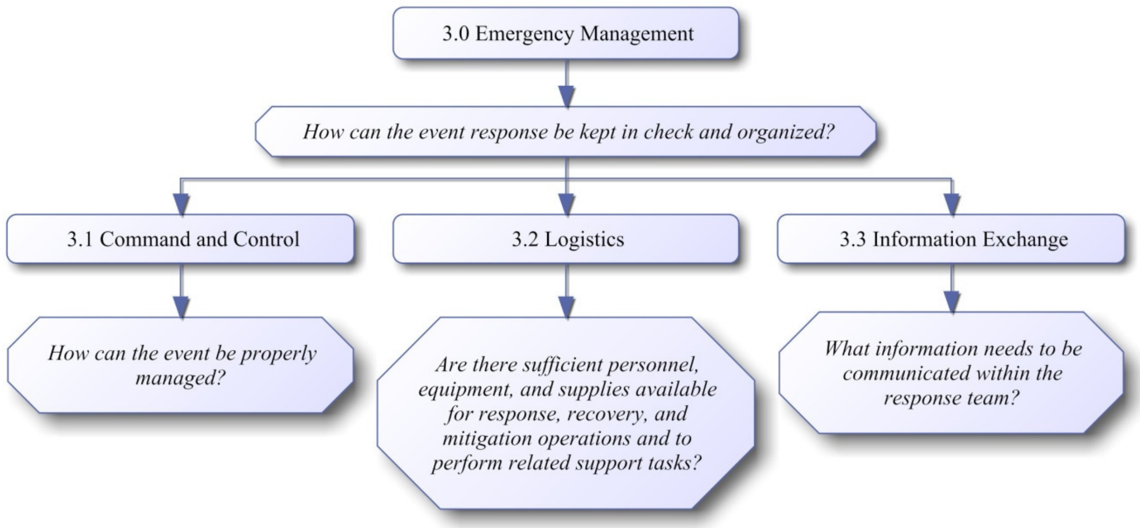
Appendix A.8: GDTA 2.2 Dispatch First Responders



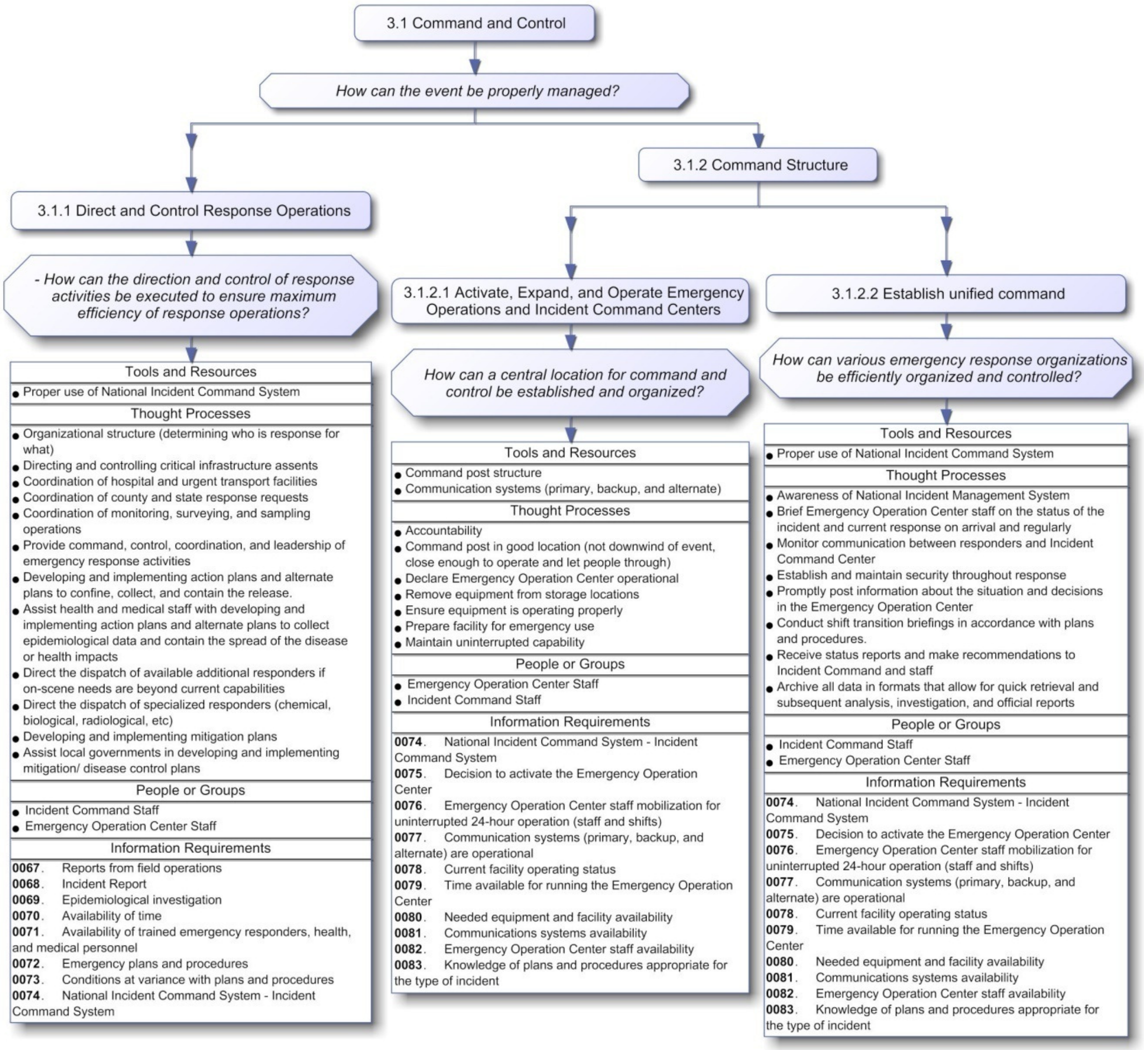
Appendix A.9: GDTA 2.3 On Scene Health and Hazard Assessment



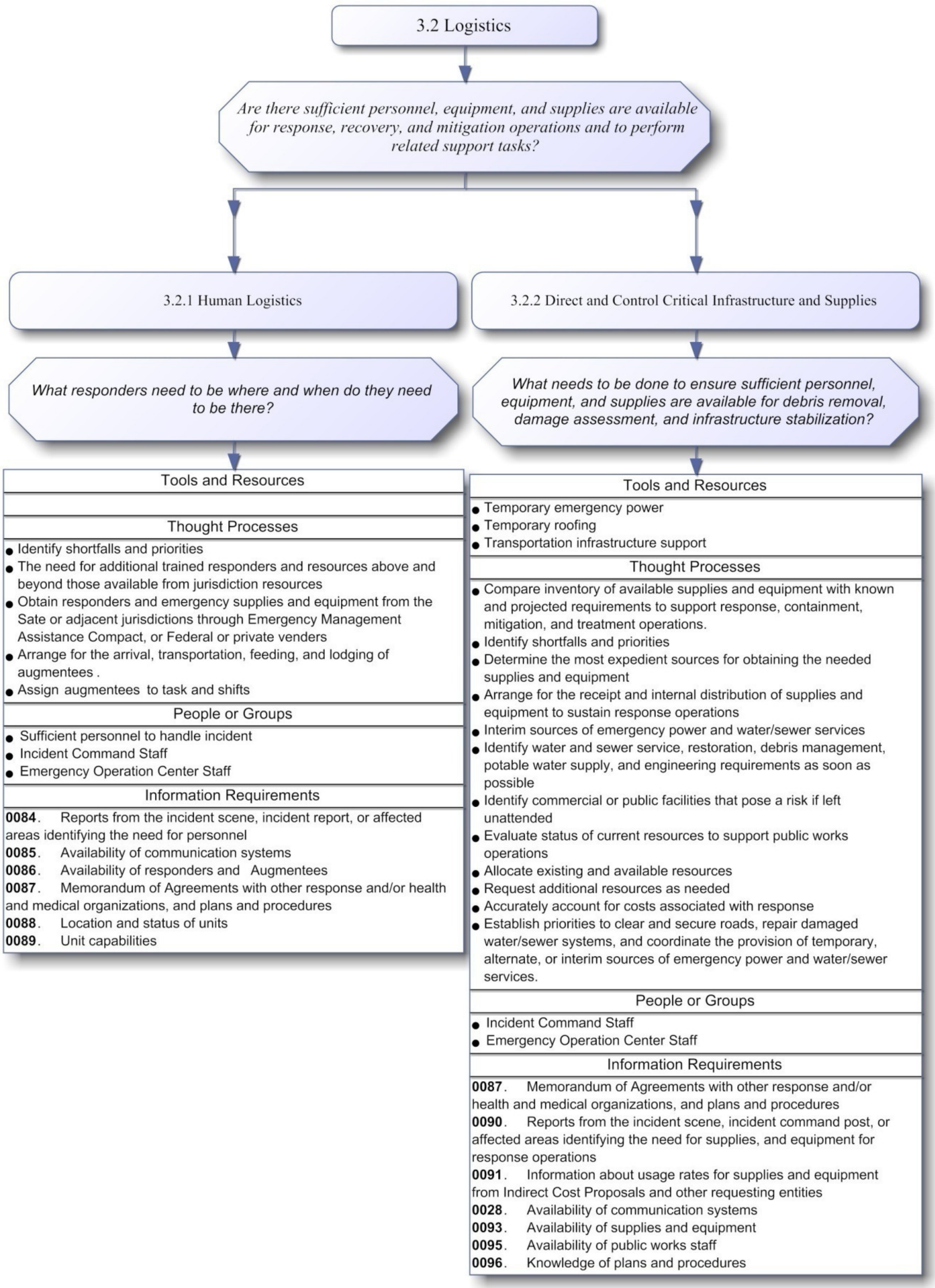
Appendix A.10: GDTA 2.4 Victim Assessment



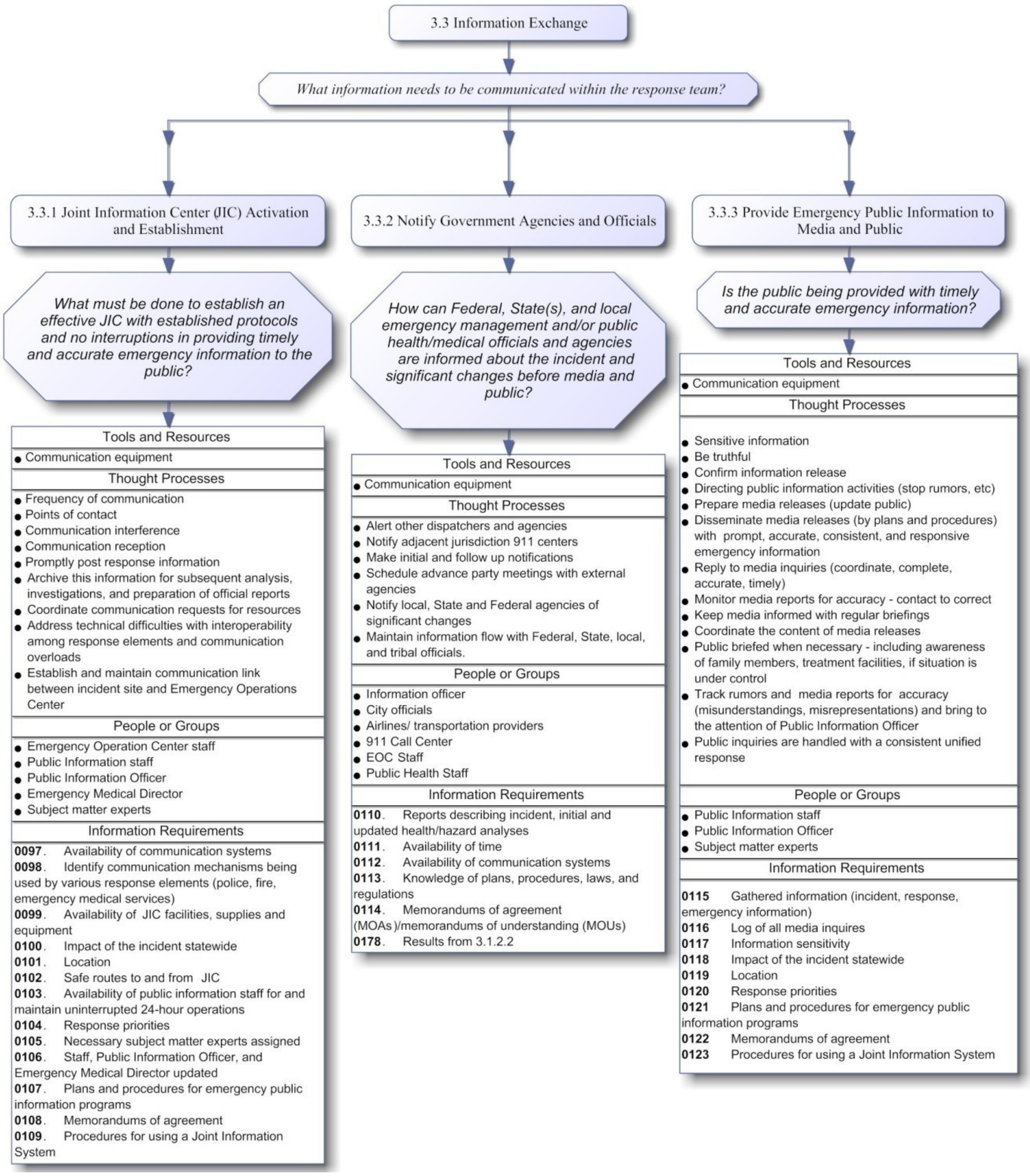
Appendix A.11: GDTA 3.0 Emergency Management



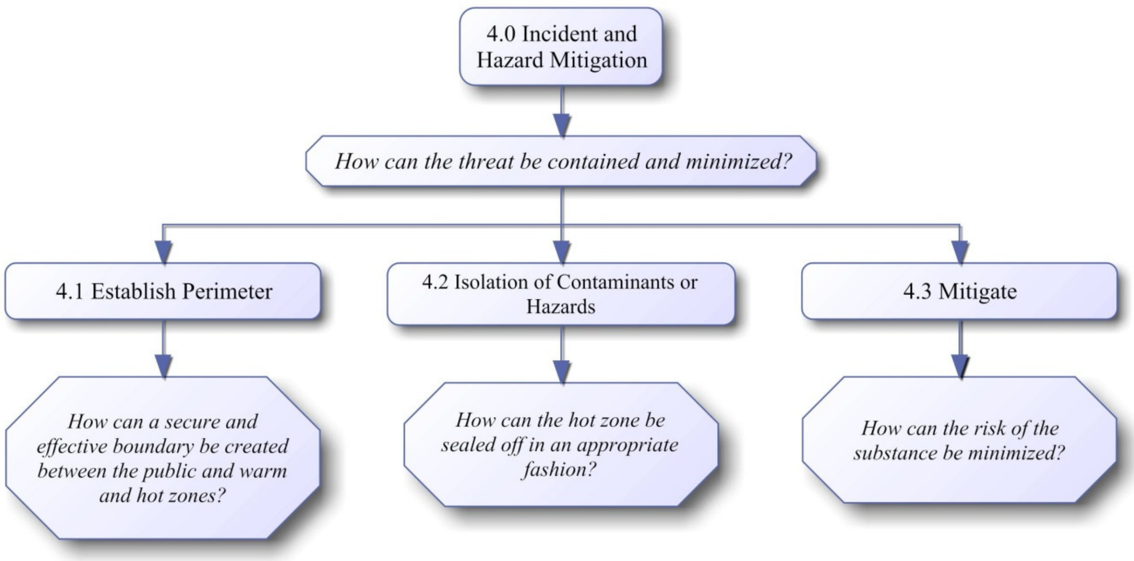
Appendix A.12: GDTA 3.1 Command and Control



Appendix A.13: GDTA3.2 Logistics



Appendix A.14: GDTA 3.3 Information Exchange



Appendix A.15: GDTA 4.0 Incident and Hazard Mitigation

4.1 Establish Perimeter

How can a secure and effective boundary be created between the public and warm and hot zones?

Tools and Resources

- Resources to create barrier
- Resources to enforce perimeter
- Resources to monitor perimeter
- Weather service (weather conditions)
- Access Control Points (ACPs)

Thought Processes

- Entry/exit procedures
- Qualifications to enter hot zone (from personnel/civilians)
- Use of staging areas
- Use of decontamination lines
- Cordon off area
- (Radiation incident) address and implement potassium iodide (KI)
- Consider resources being brought to scene
- Be aware of panic/fear
- Site security
- Knowledge of local geography
- Knowledge of local street patterns
- Ensure access control for responders
- Search the area for secondary devices
- Person Protective Equipment for your first responders

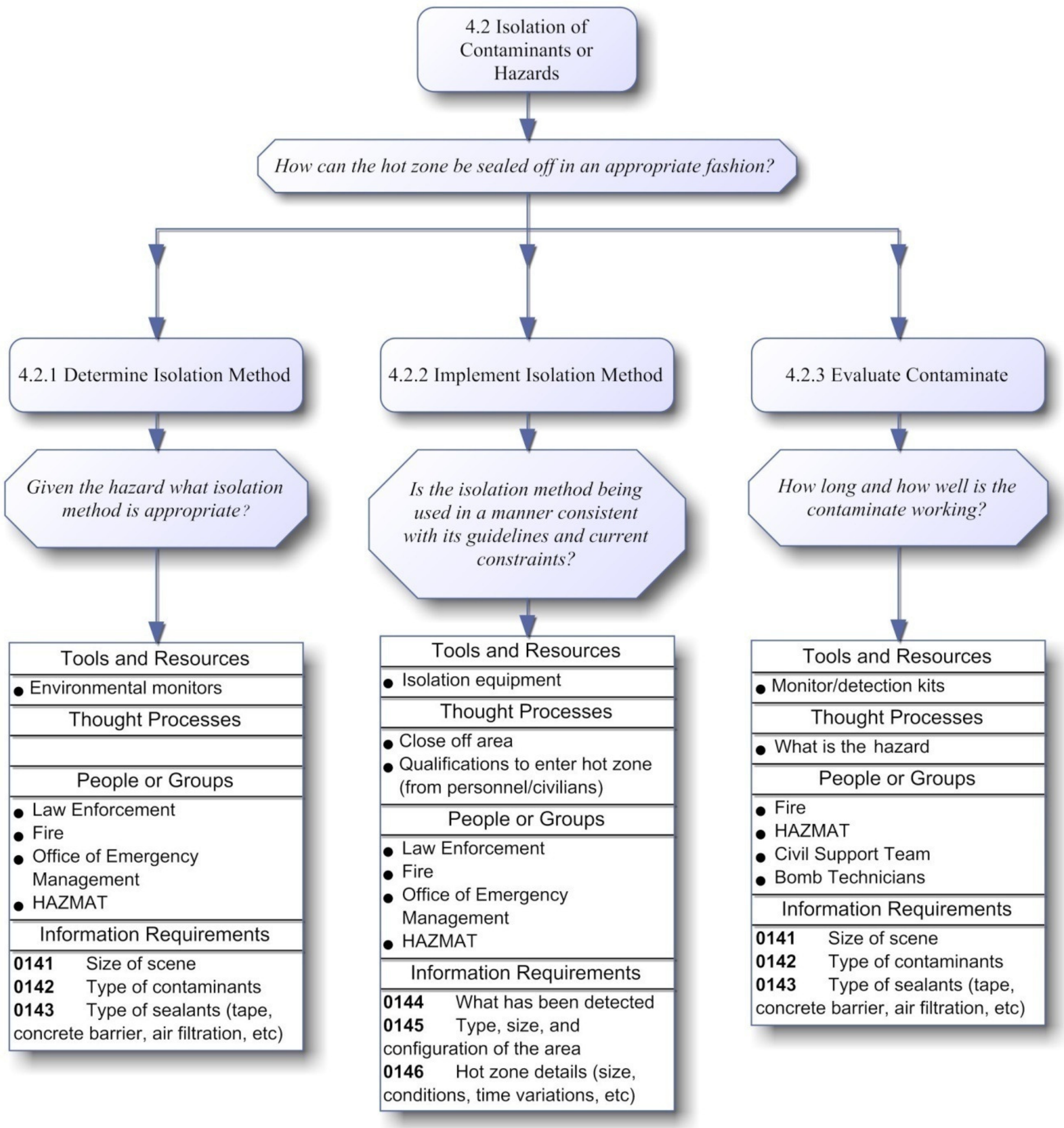
People or Groups

- Law Enforcement
- Office of Emergency Management
- Public Works

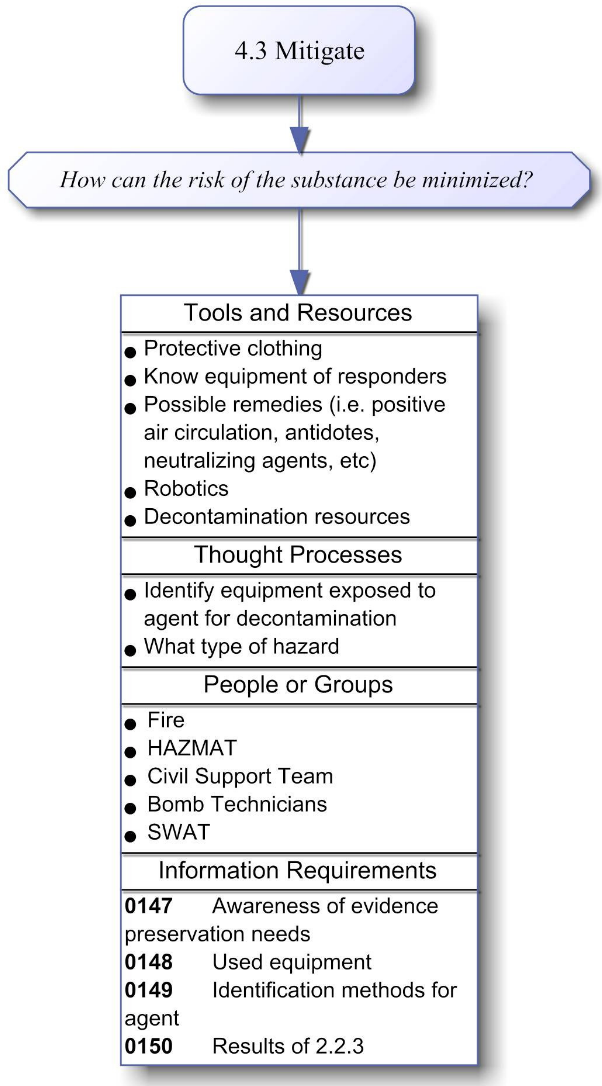
Information Requirements

0124	Available and necessary Person Protective Equipment
0125	Type of event
0126	Number of people
0127	Size of scene
0128	Location of event
0129	Type of situation
0130	Weather and environmental conditions
0131	Wind direction and speed
0132	Awareness of secondary devices
0133	Selected evacuation routes
0134	Defined predicted hazard area
0135	Availability of time
0136	Availability of communication systems
0137	Availability of personnel
0138	Availability of vehicles, barricades, and other traffic control equipment
0139	Pertinent maps, diagrams, and plans
0140	Simulations at variance with assumptions in plans and procedures
0180	Traffic Prediction Report

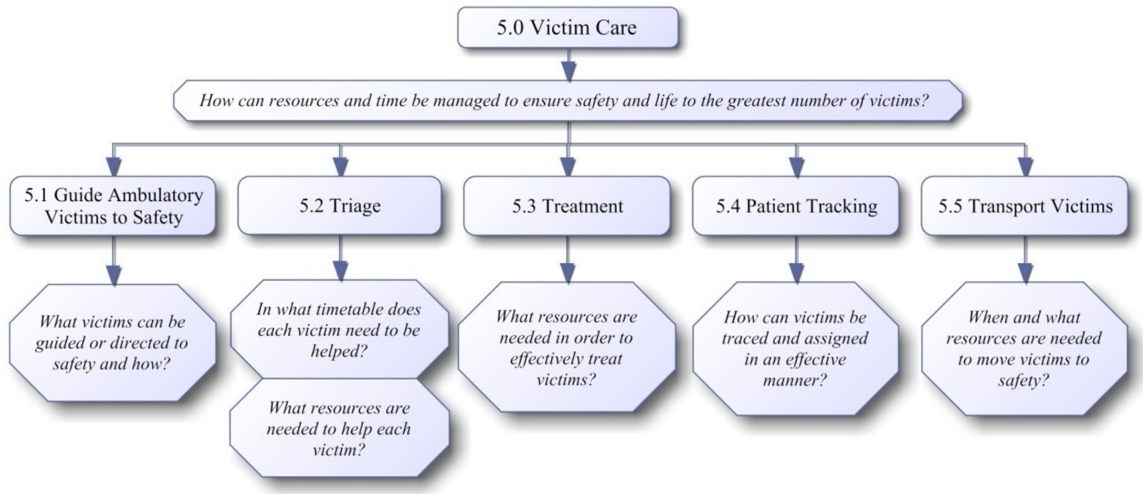
Appendix A.16: GDTA 4.1 Establish Perimeter



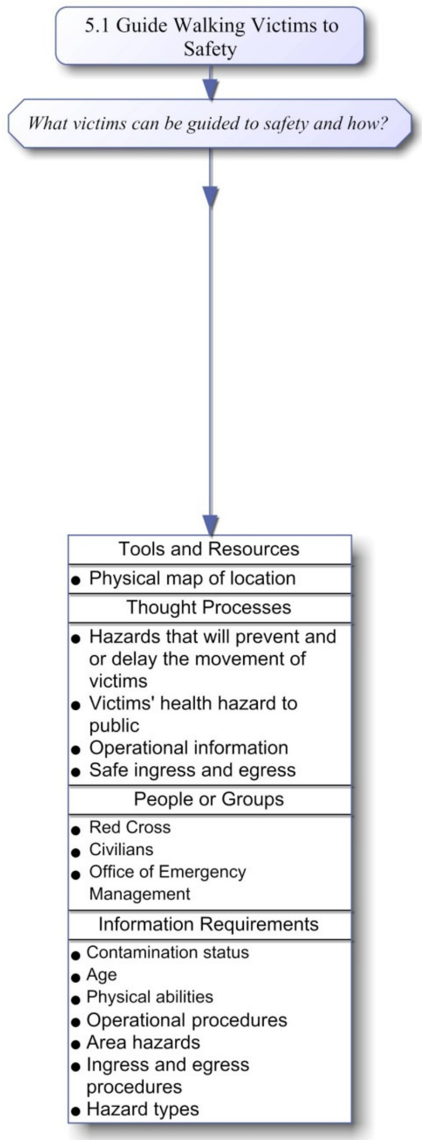
Appendix A.17: GDTA 4.2 Isolation of Contaminates or Hazards



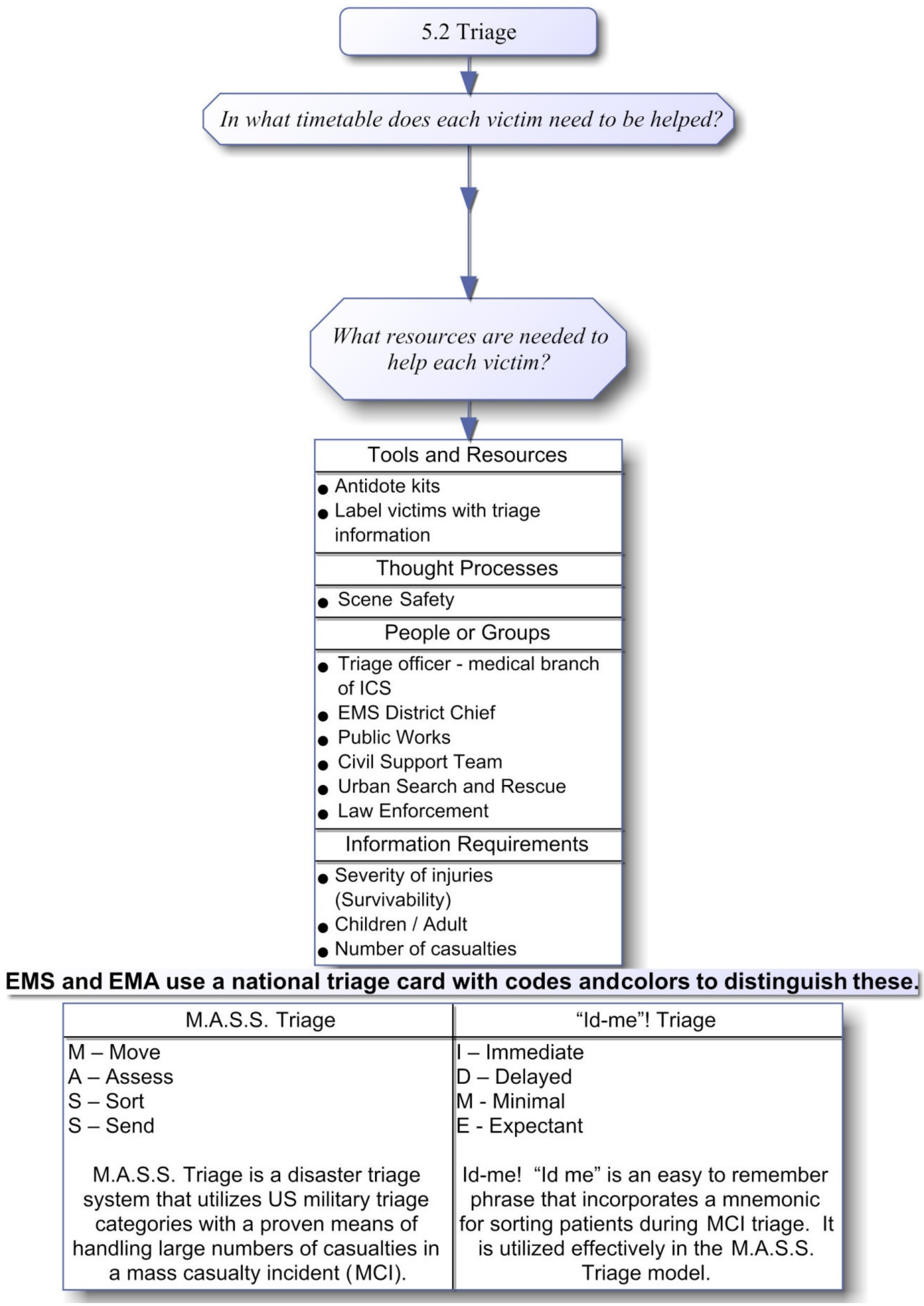
Appendix A.18: GDTA 4.3 Mitigate



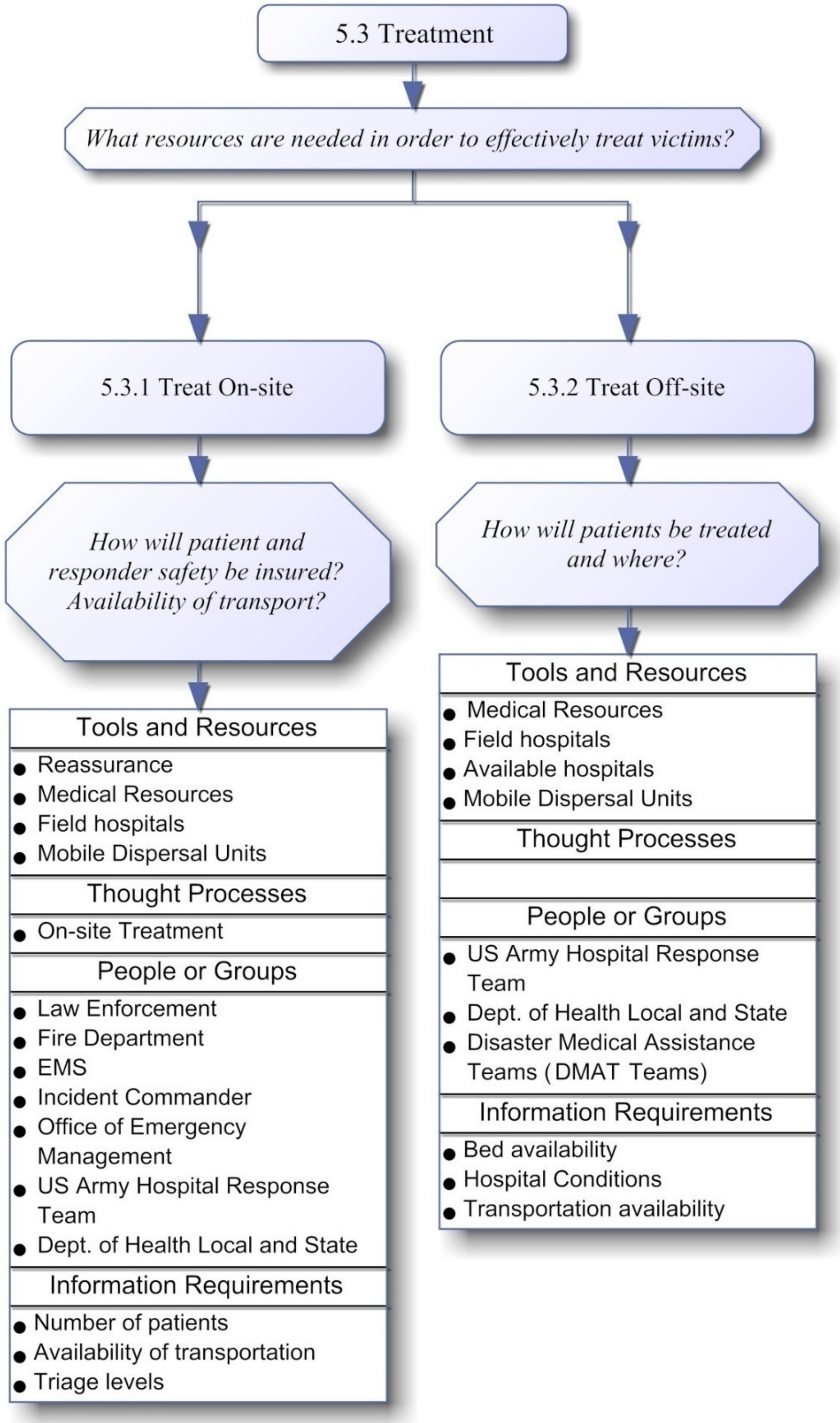
Appendix A.19: GDTA 5.0 Victim Care



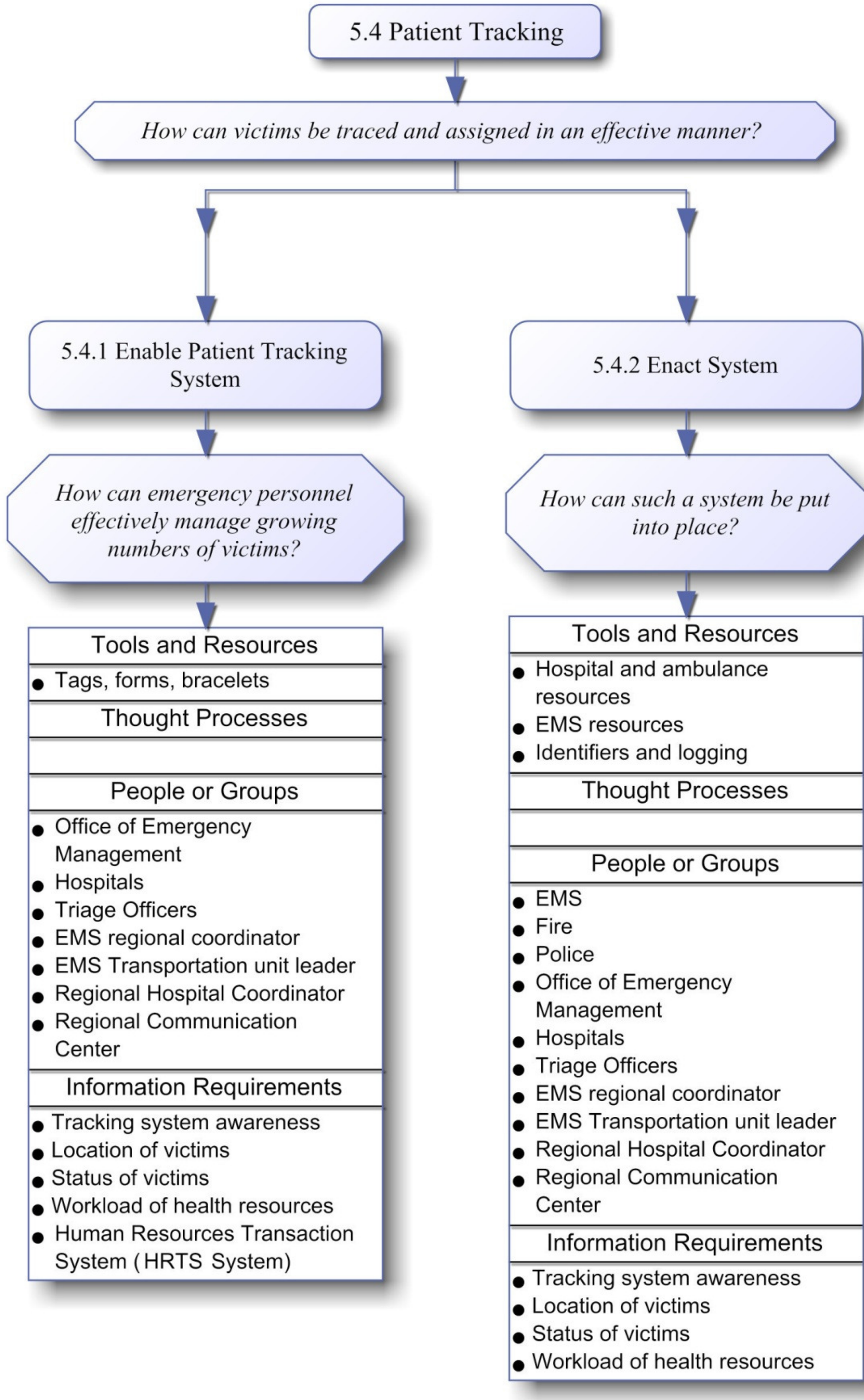
Appendix A.20: GDTA 5.1 Guide Walking Victims to Safety



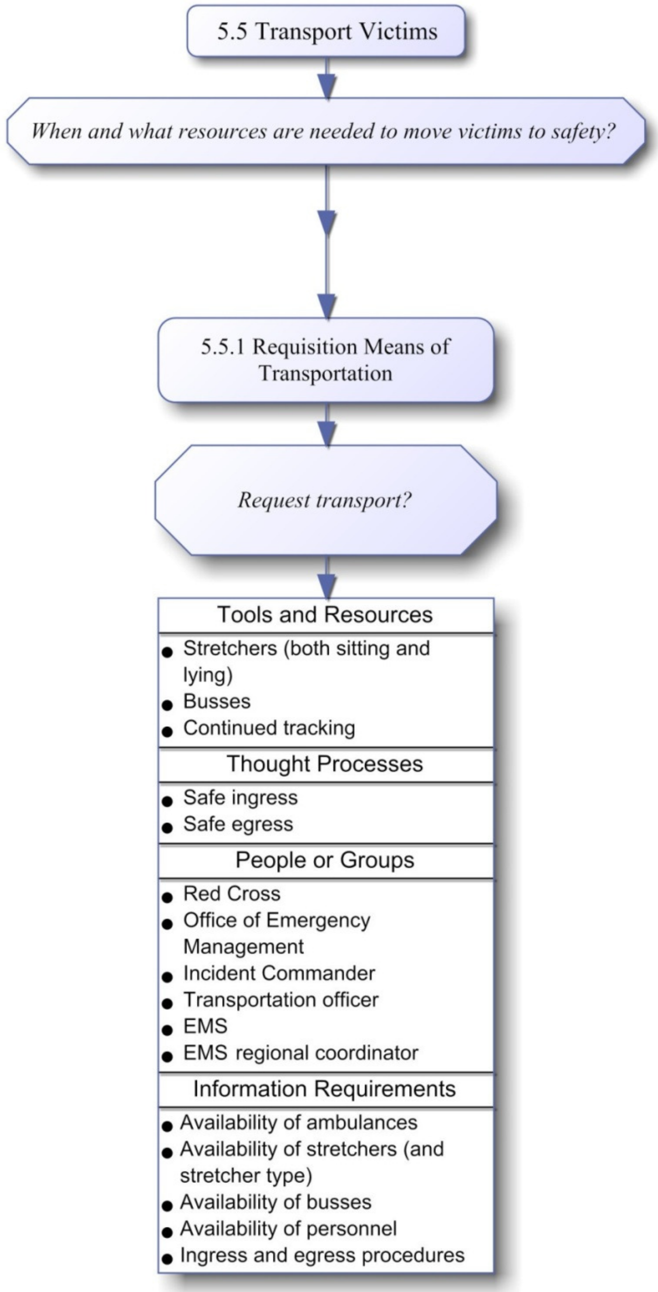
Appendix A.21: GDTA 5.2 Triage



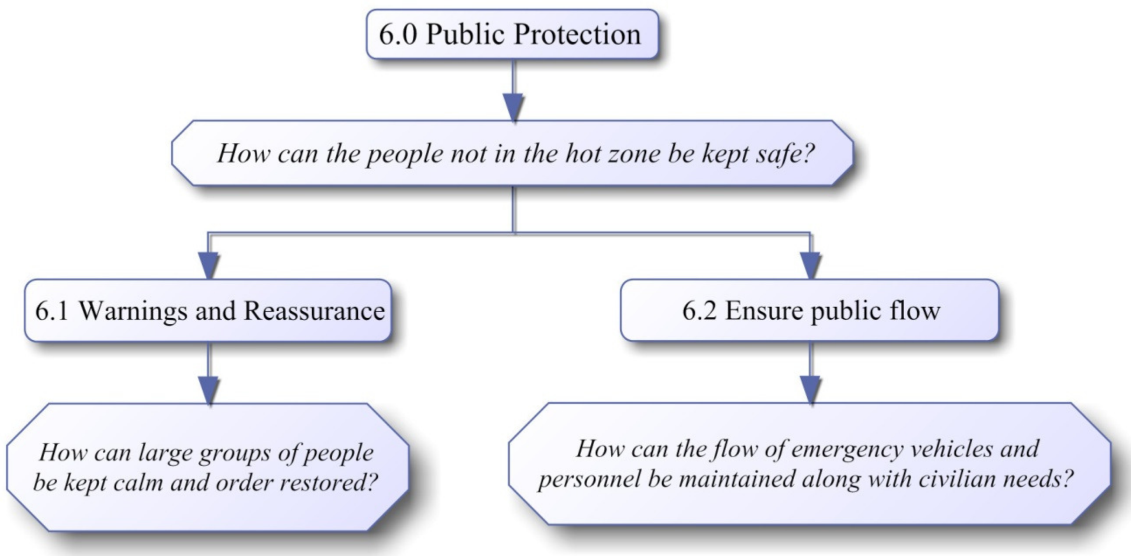
Appendix A.22: GDTA 5.3 Treatment



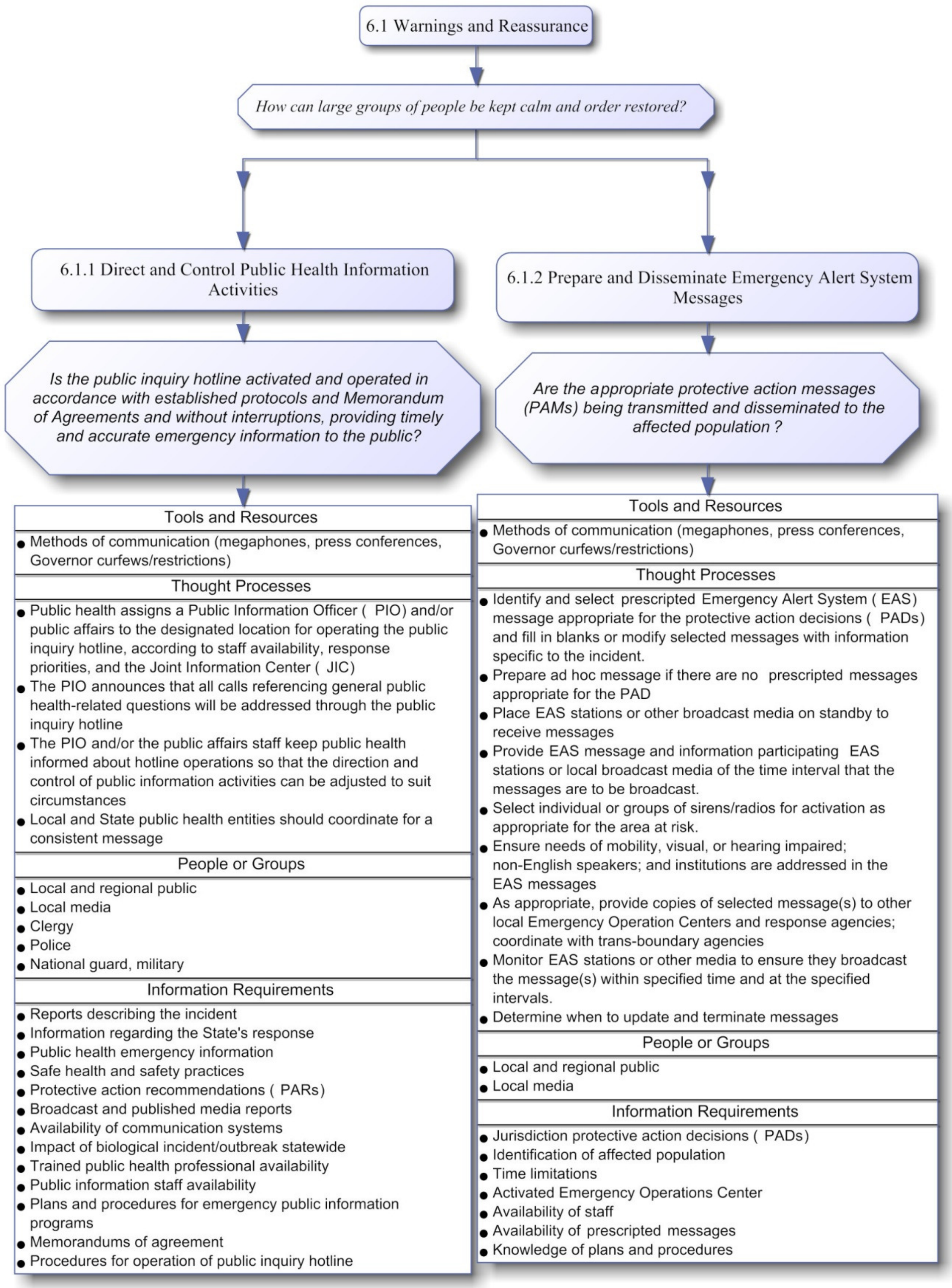
Appendix A.23: GDTA 5.4 Patient Tracking



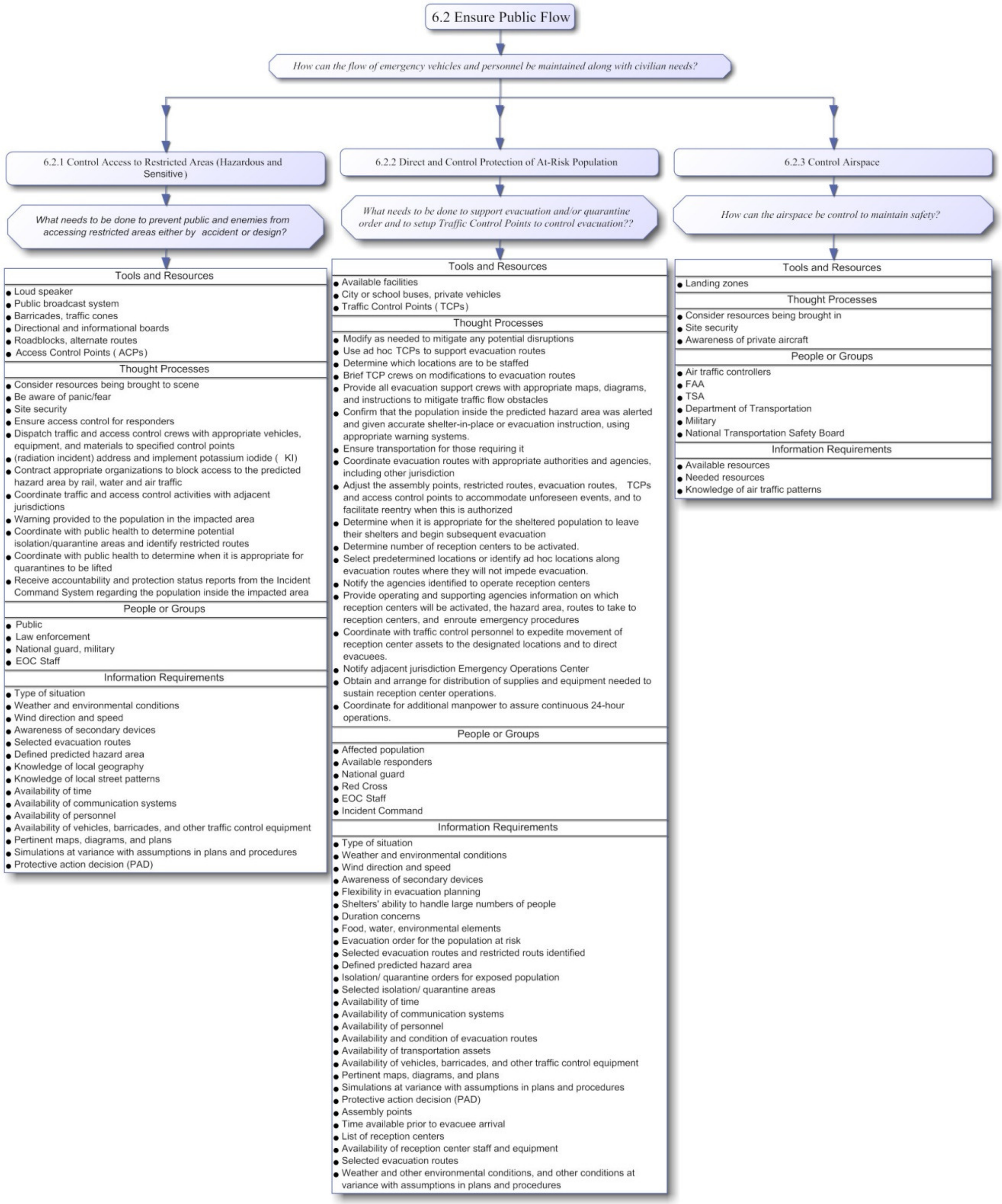
Appendix A.24: GDTA 5.5 Transport Victims



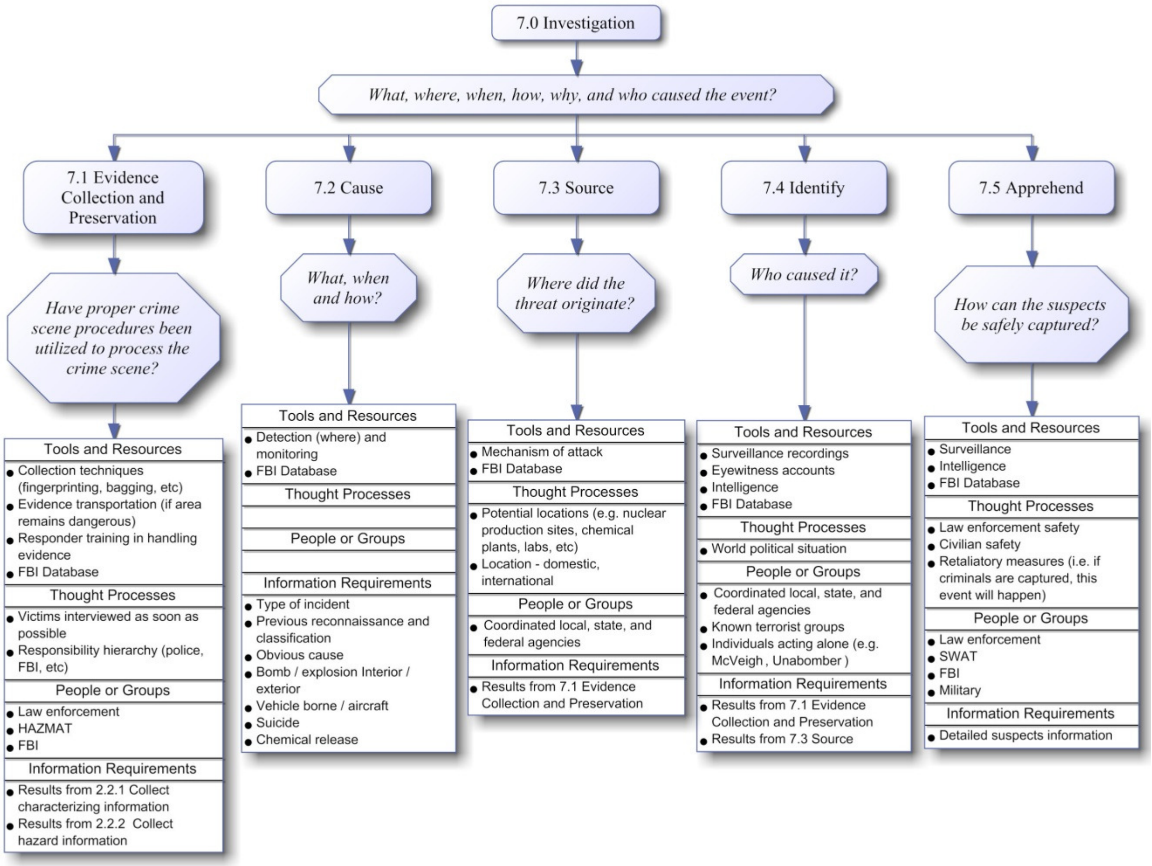
Appendix A.25: GDTA 6.0 Public Protection



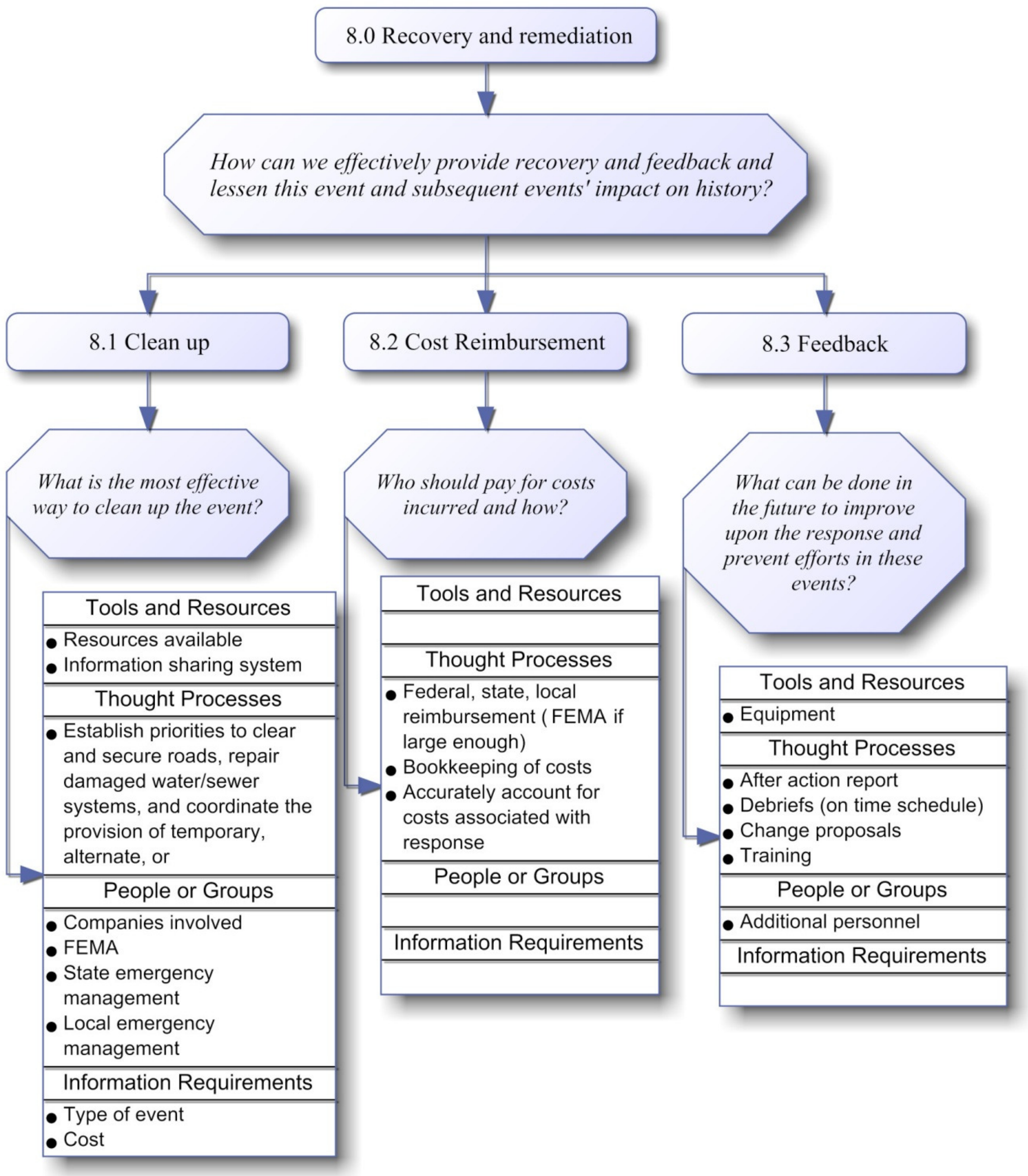
Appendix A.26: GDTA 6.1 Warnings and Reassurance



Appendix A.27: GDTA 6.2 Ensure Public Flow

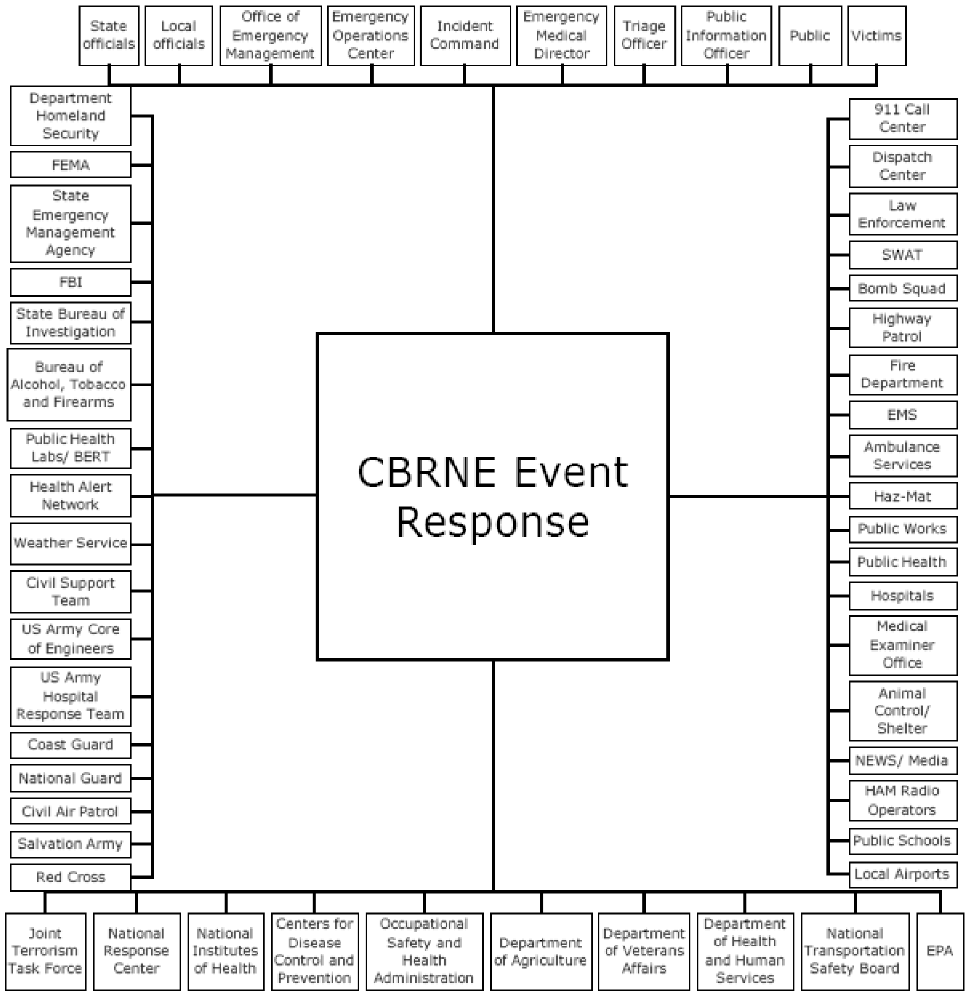


Appendix A.28: GDTA 7.0 Investigation

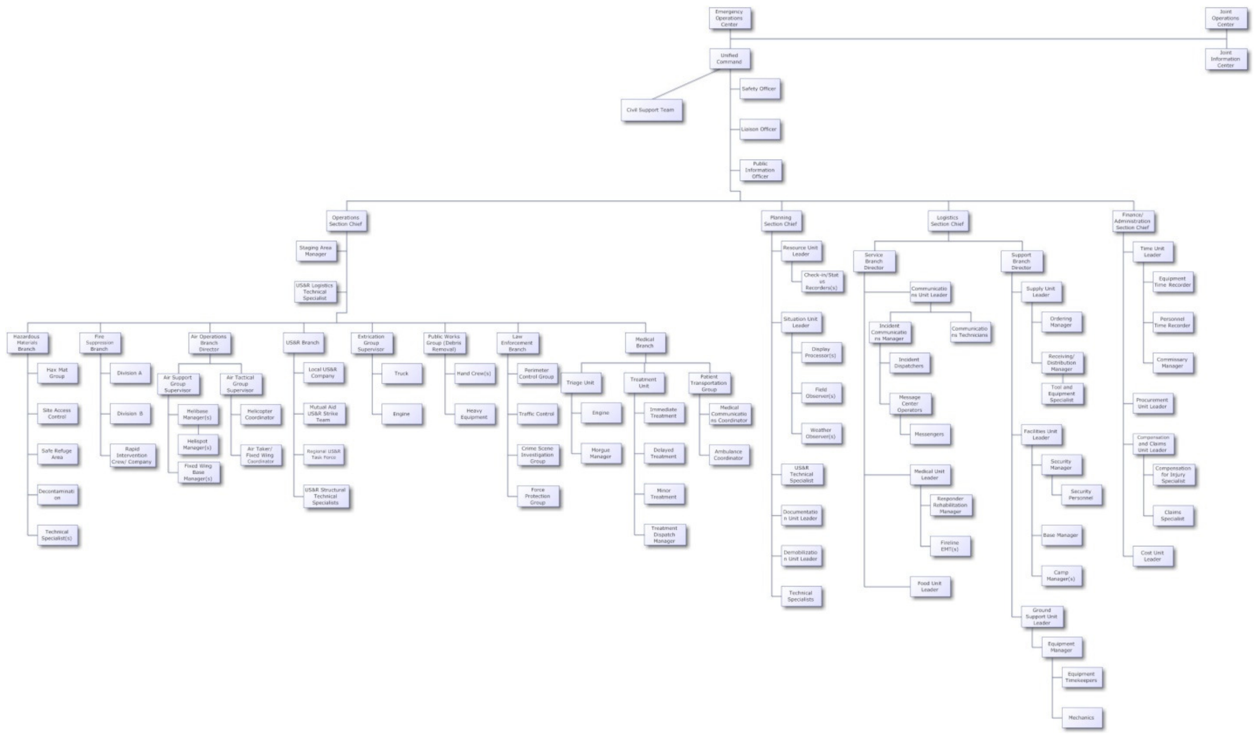


Appendix A.29: GDTA 8.0 Recovery and Remediation

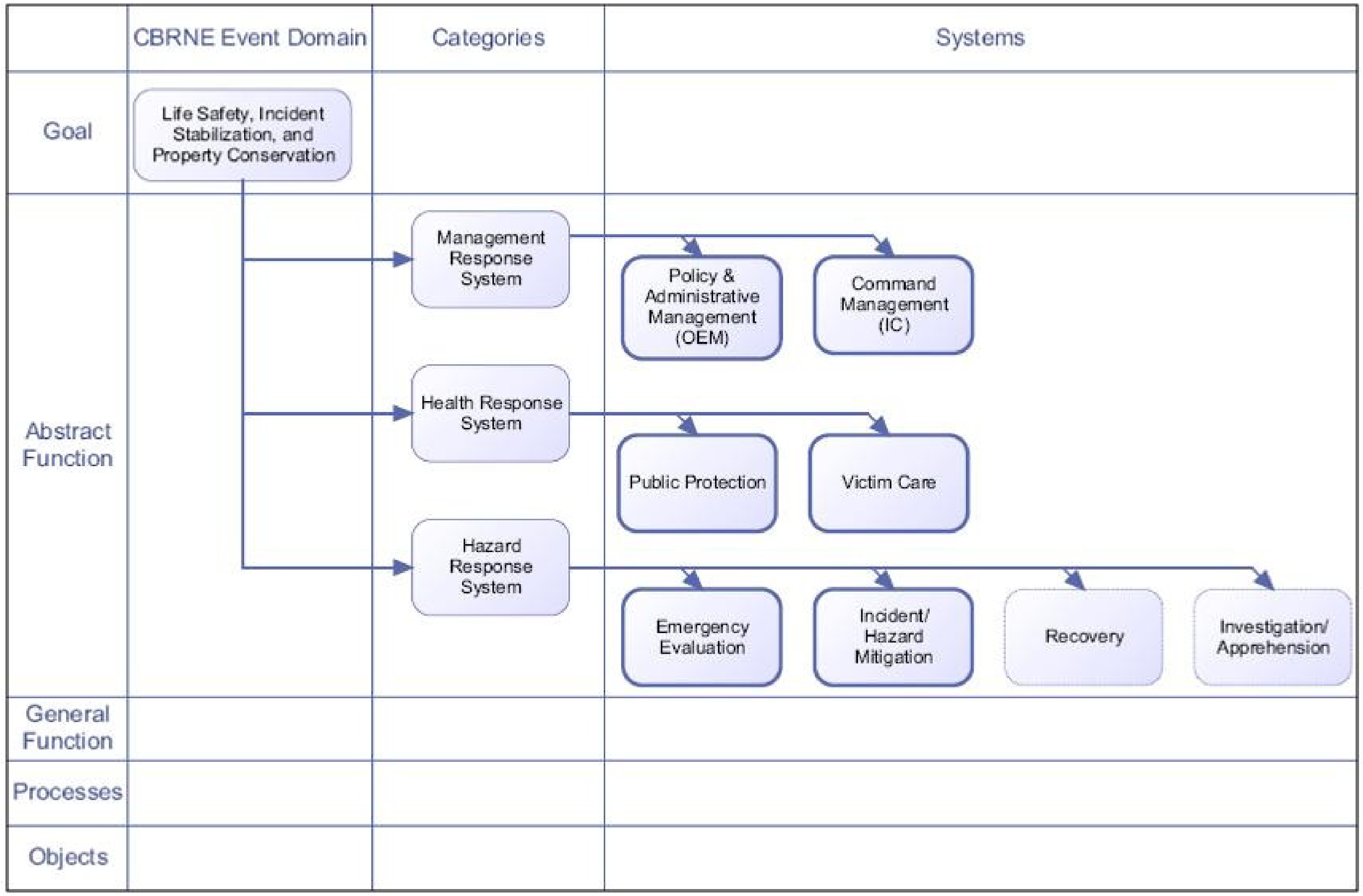
APPENDIX B: THE COMPLETE RESULTS OF THE MCWA.



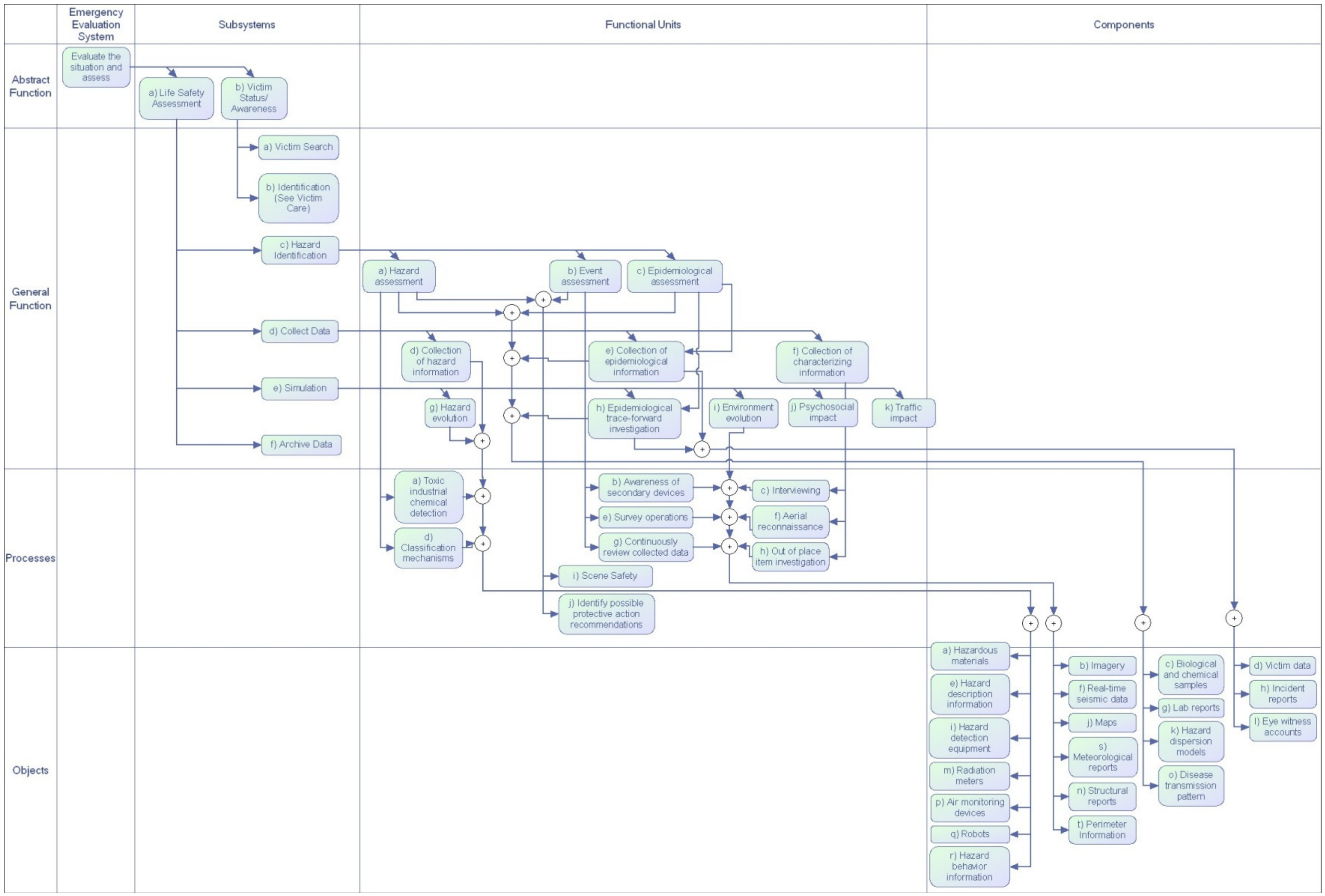
Appendix B.1: Relevant Social Groups



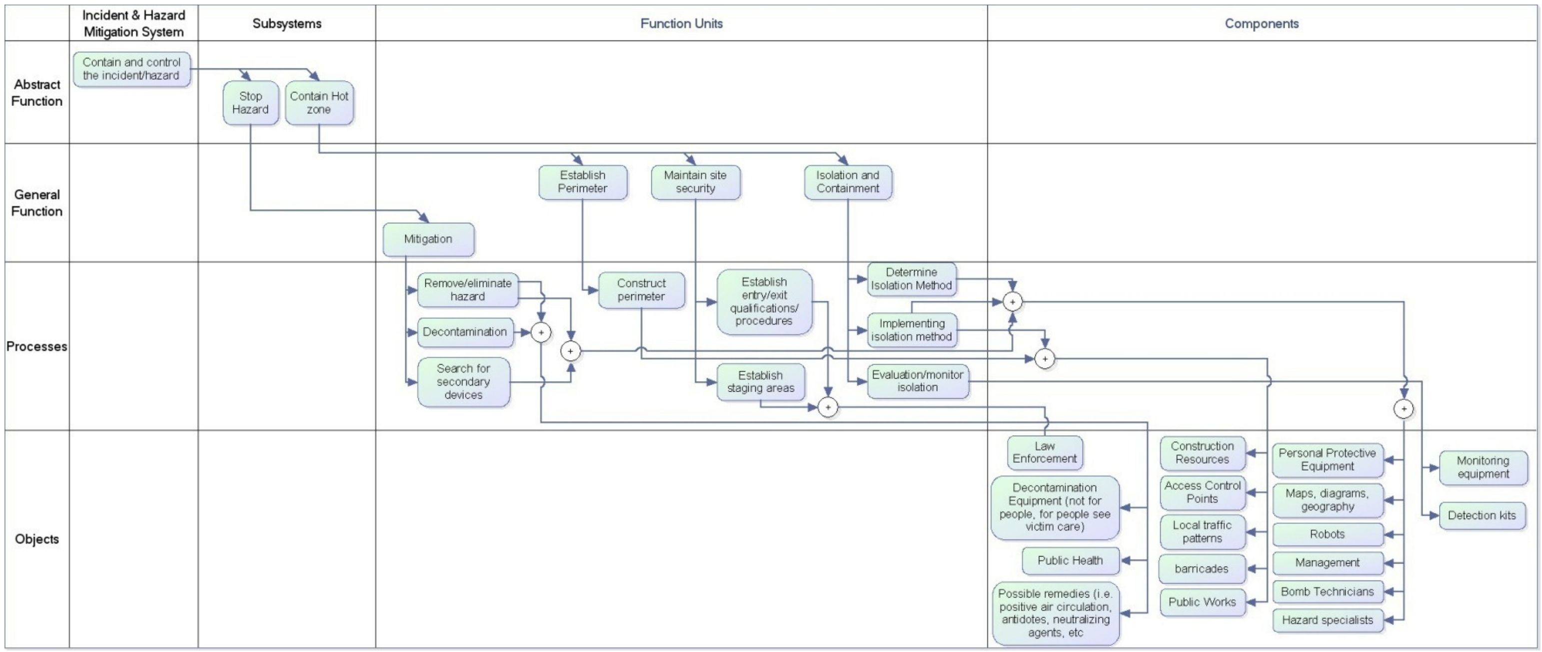
Appendix B.2: Communication Flow Map



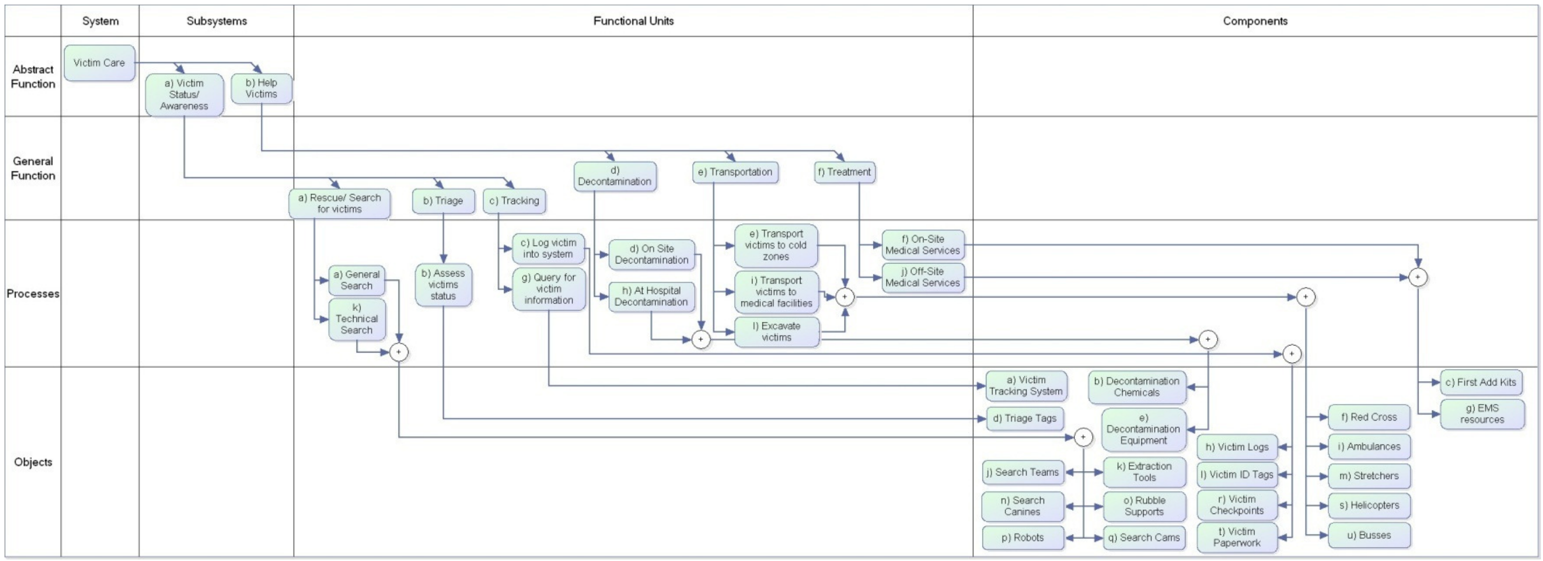
Appendix B.3: WDA Overview



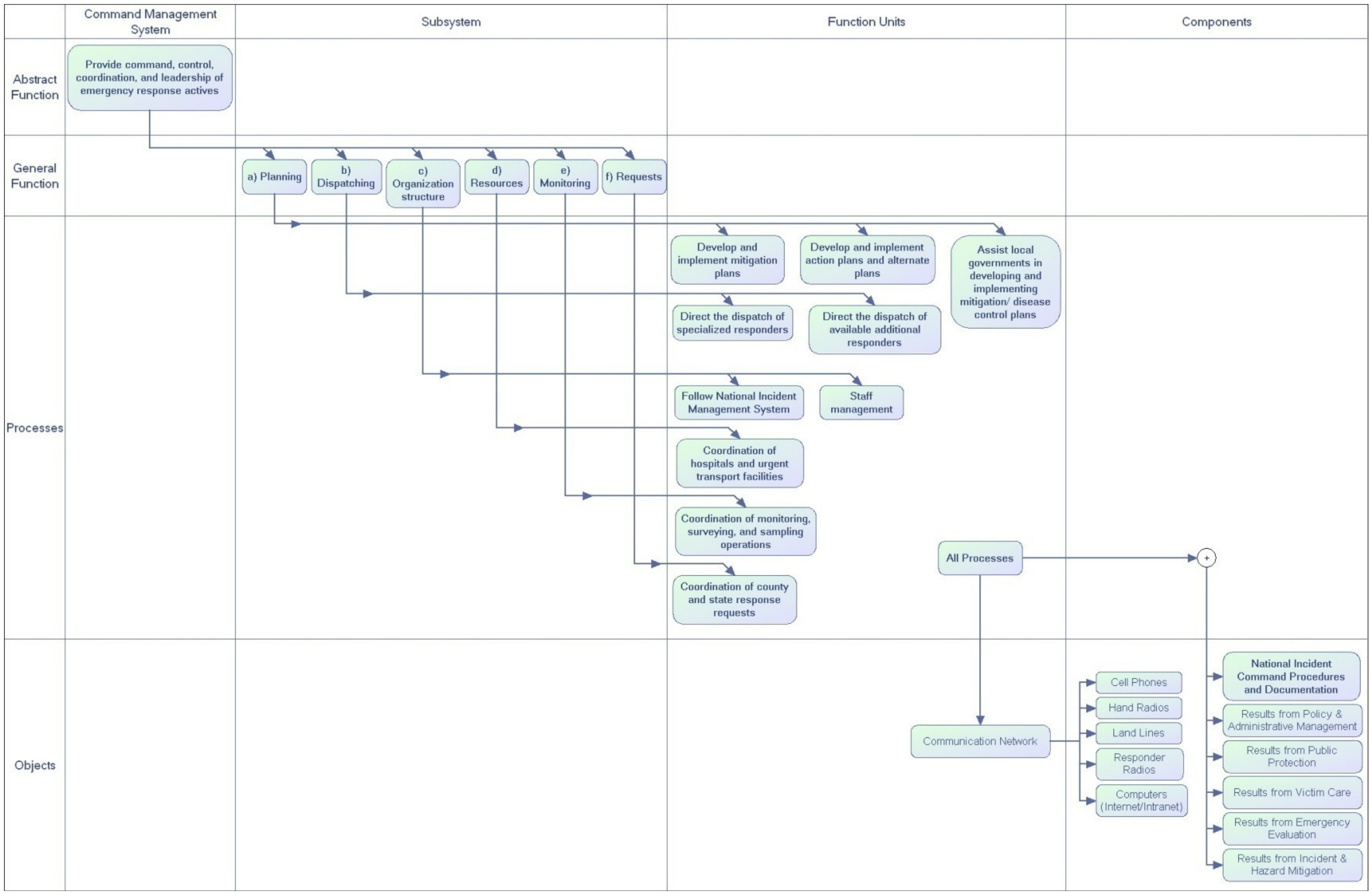
Appendix B.4: WDA Emergency Evaluation System



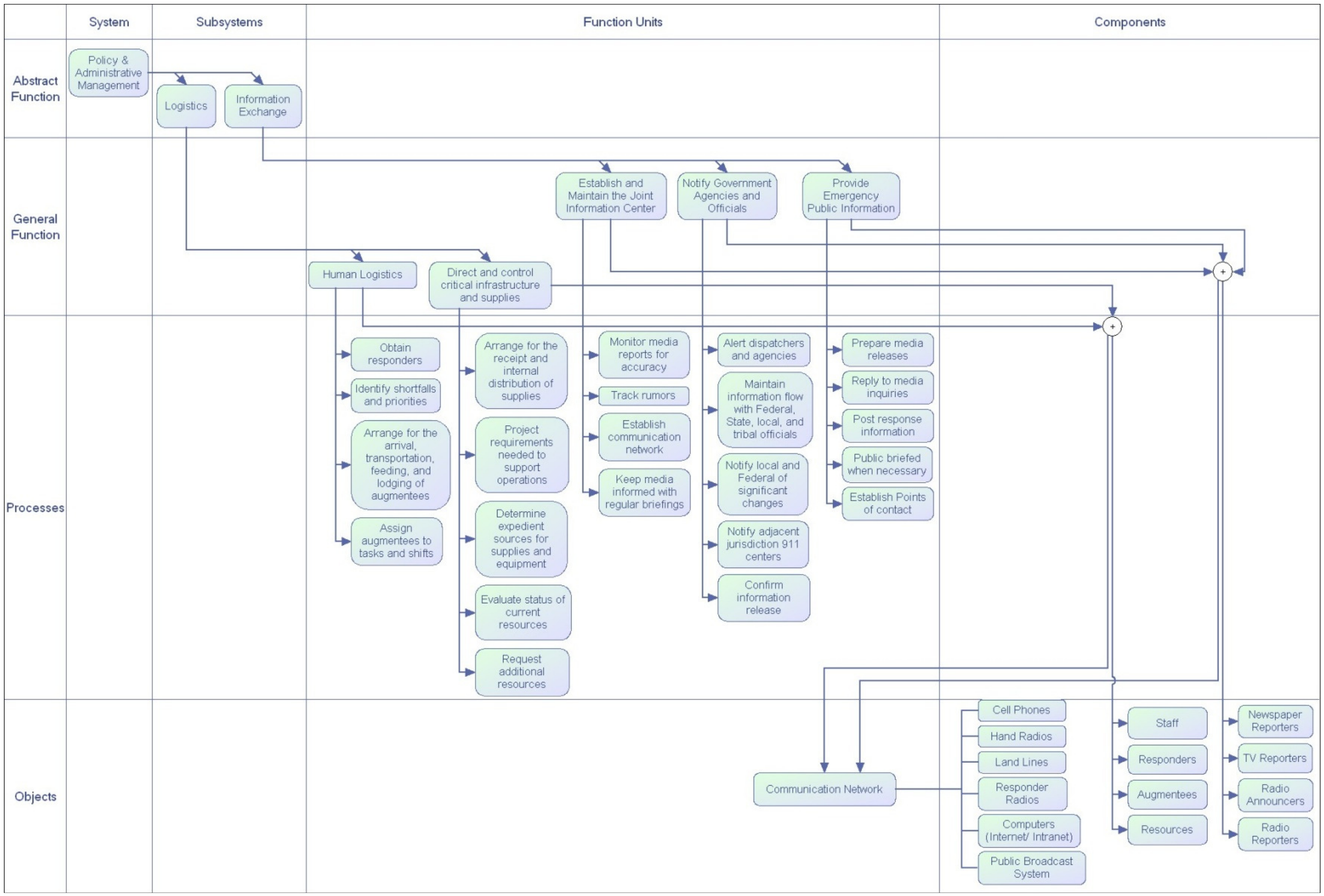
Appendix B.5: WDA Incident and Hazard Migration System



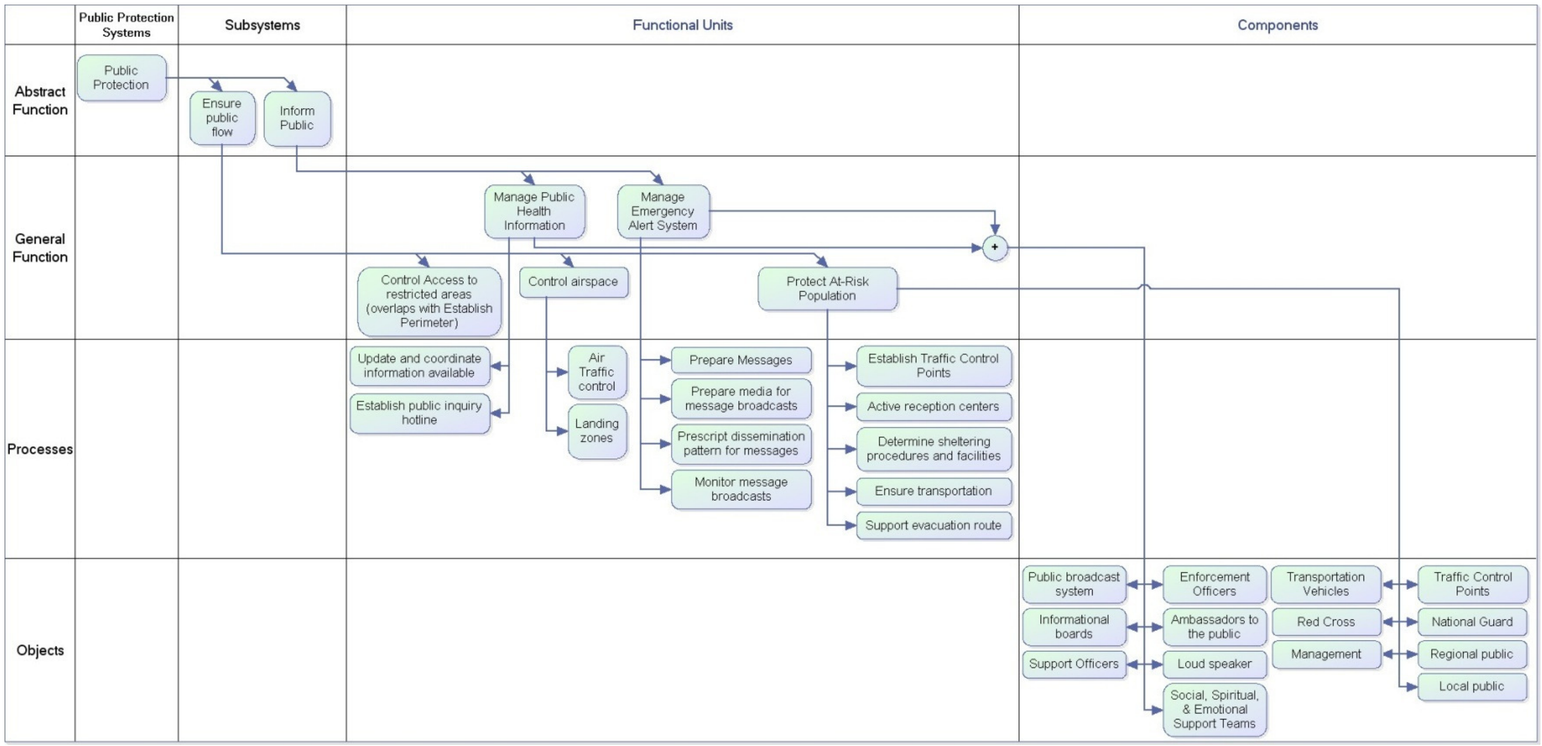
Appendix B.6: WDA Victim Care



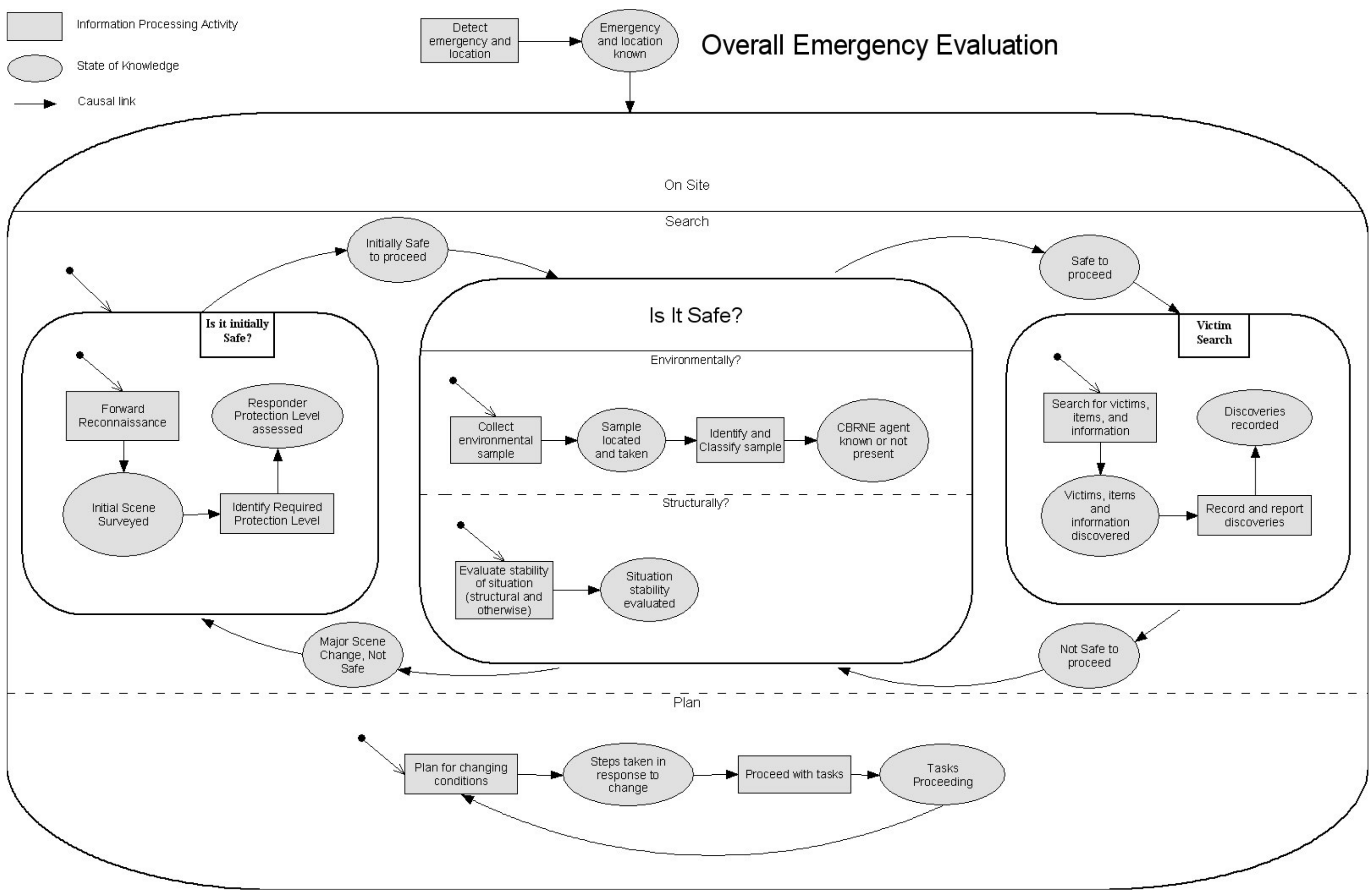
Appendix B.7: WDA Command Management



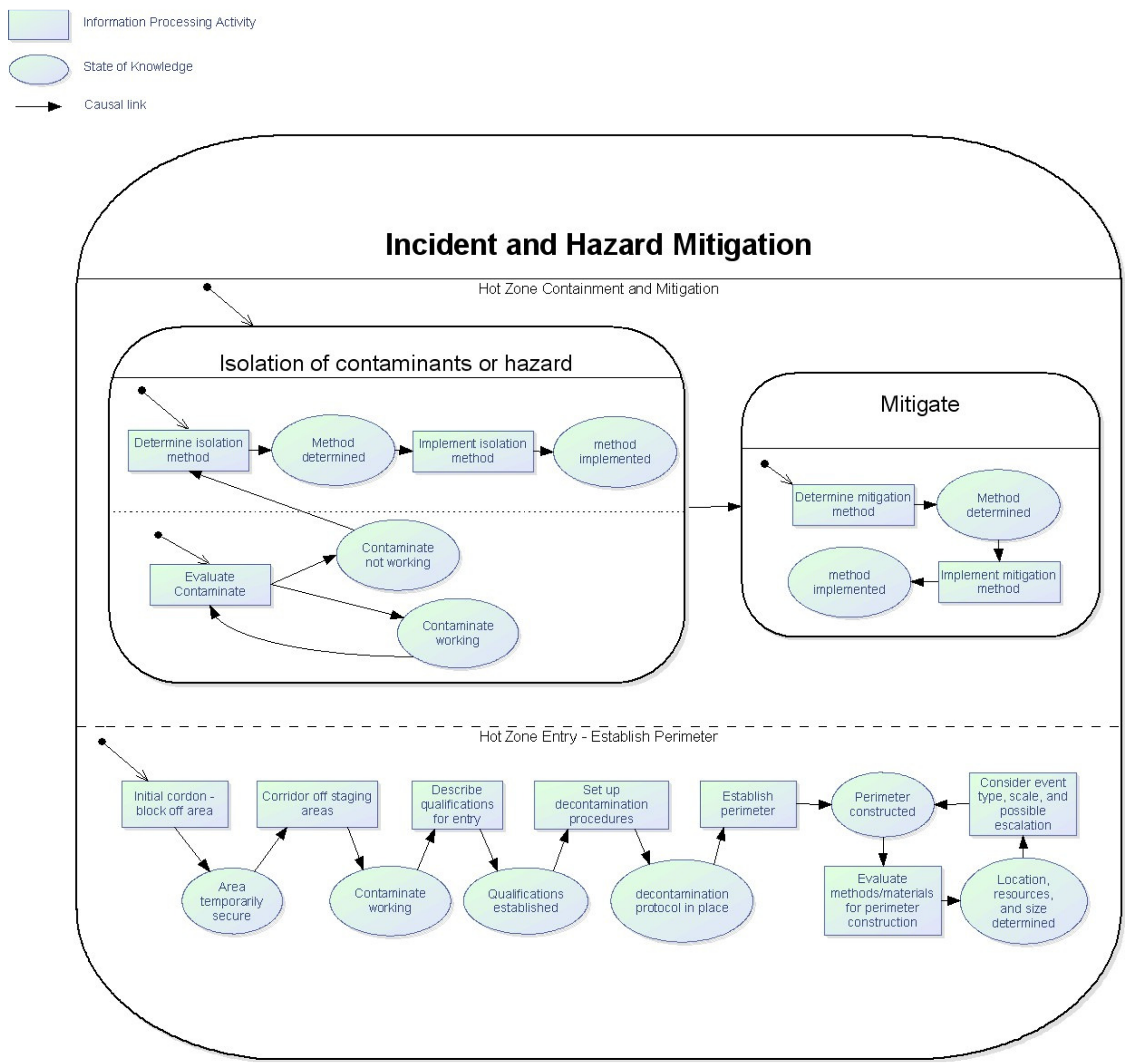
Appendix B.8: WDA Policy and Administrative Management



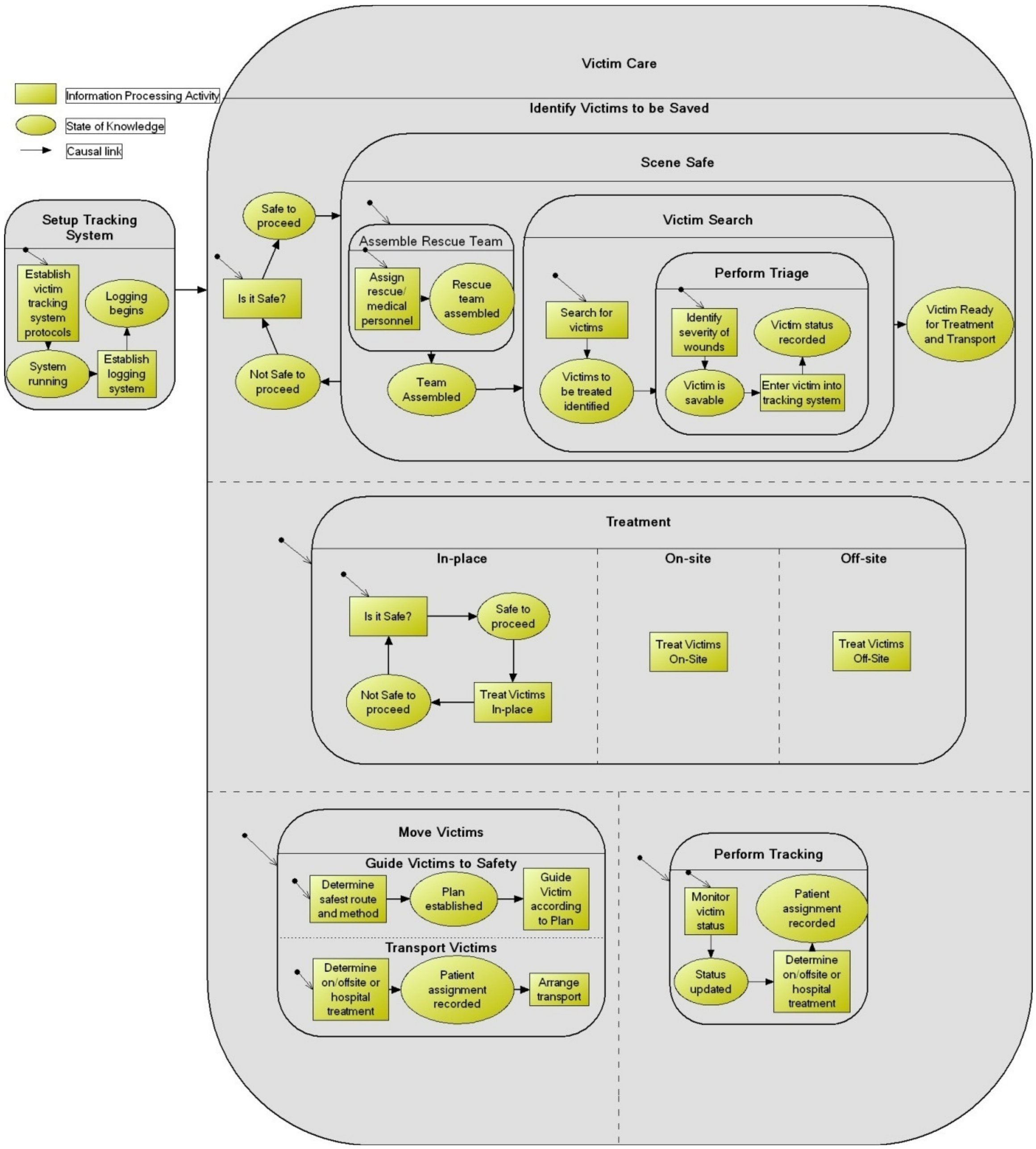
Appendix B.9: WDA Public Protection



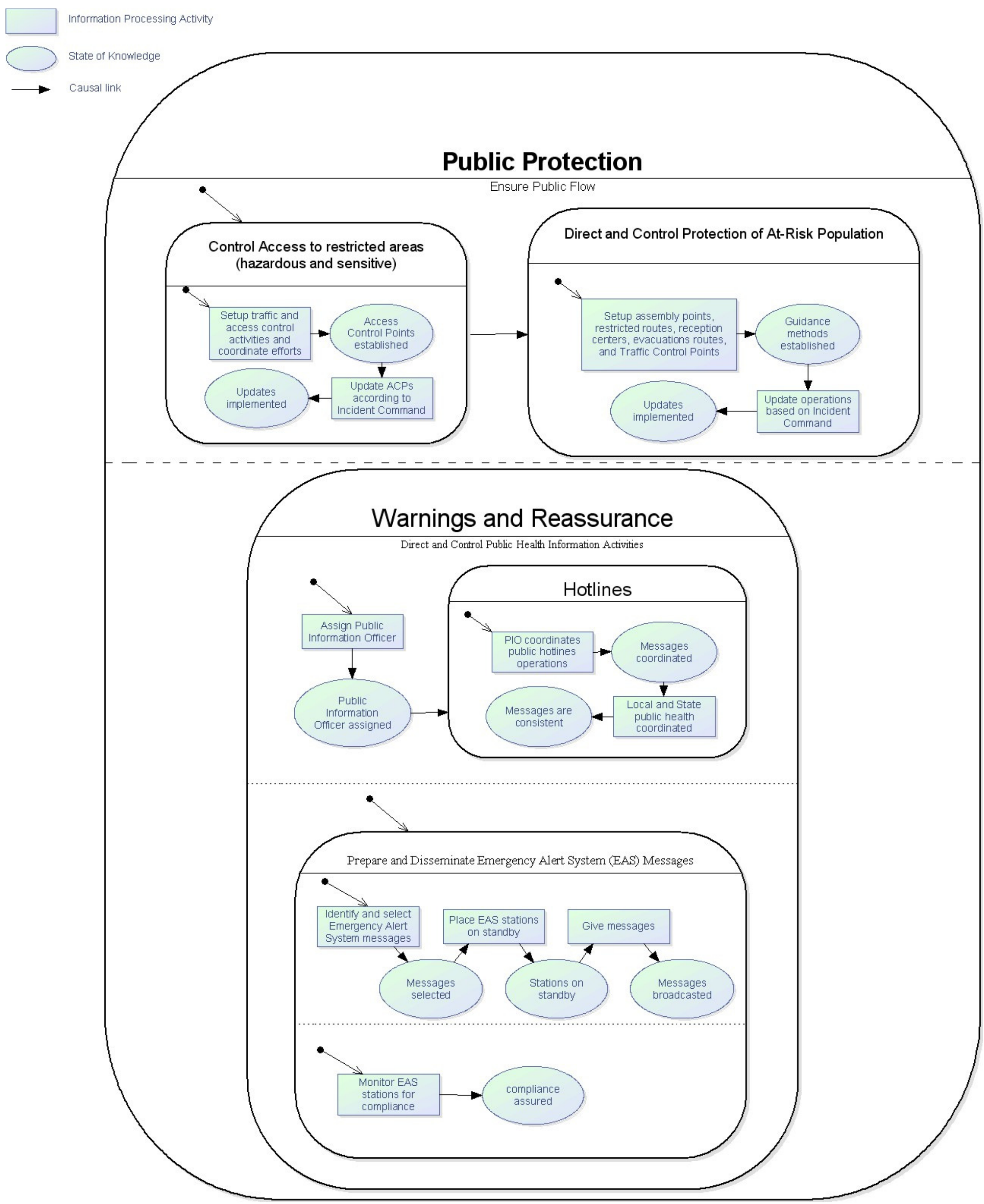
Appendix B.10: CbTA Statecharts: Overall Emergency Evaluation



Appendix B.11: CbTA Statecharts: Incident and Hazard Mitigation

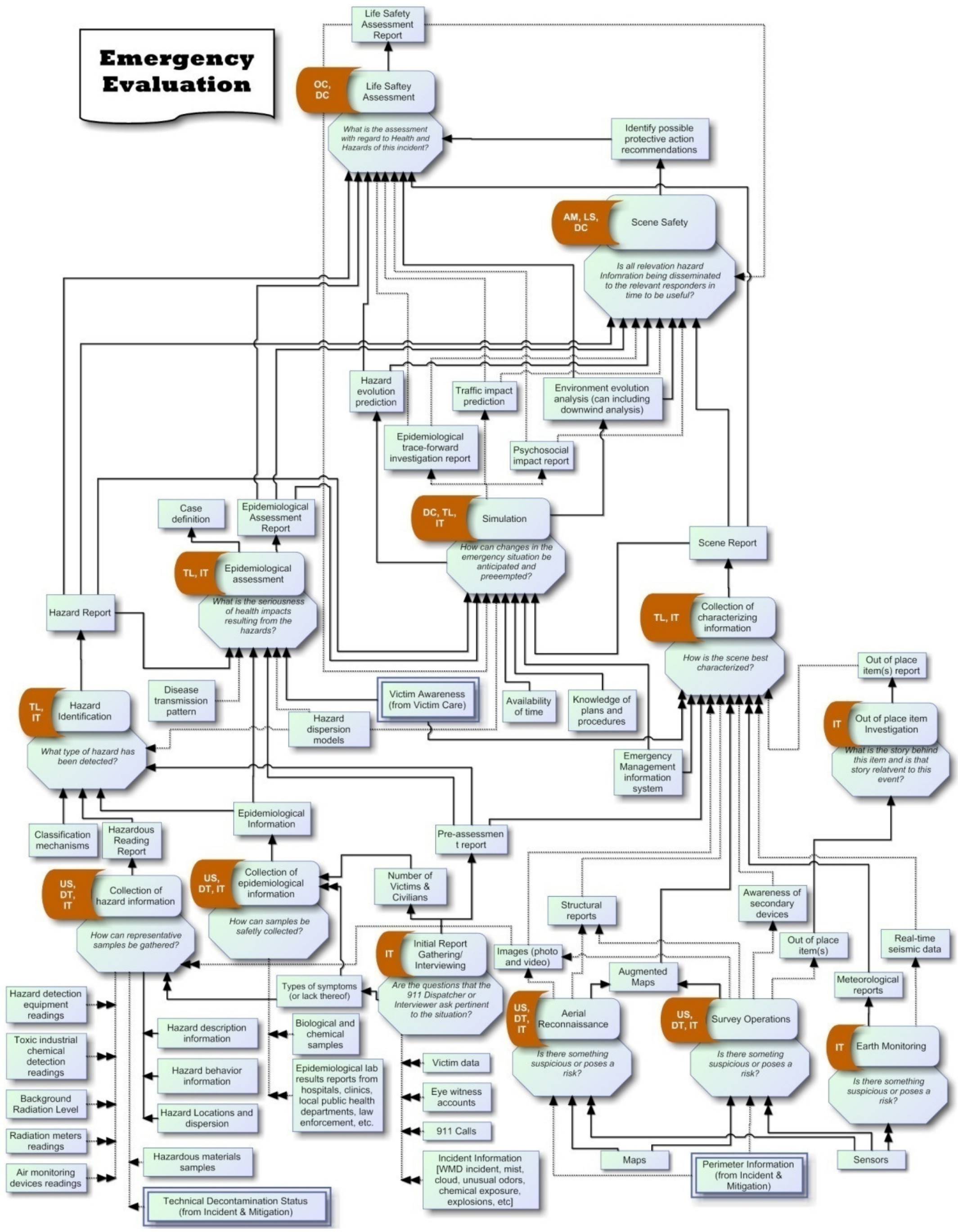


Appendix B.12: CbTA Statecharts: Victim Care

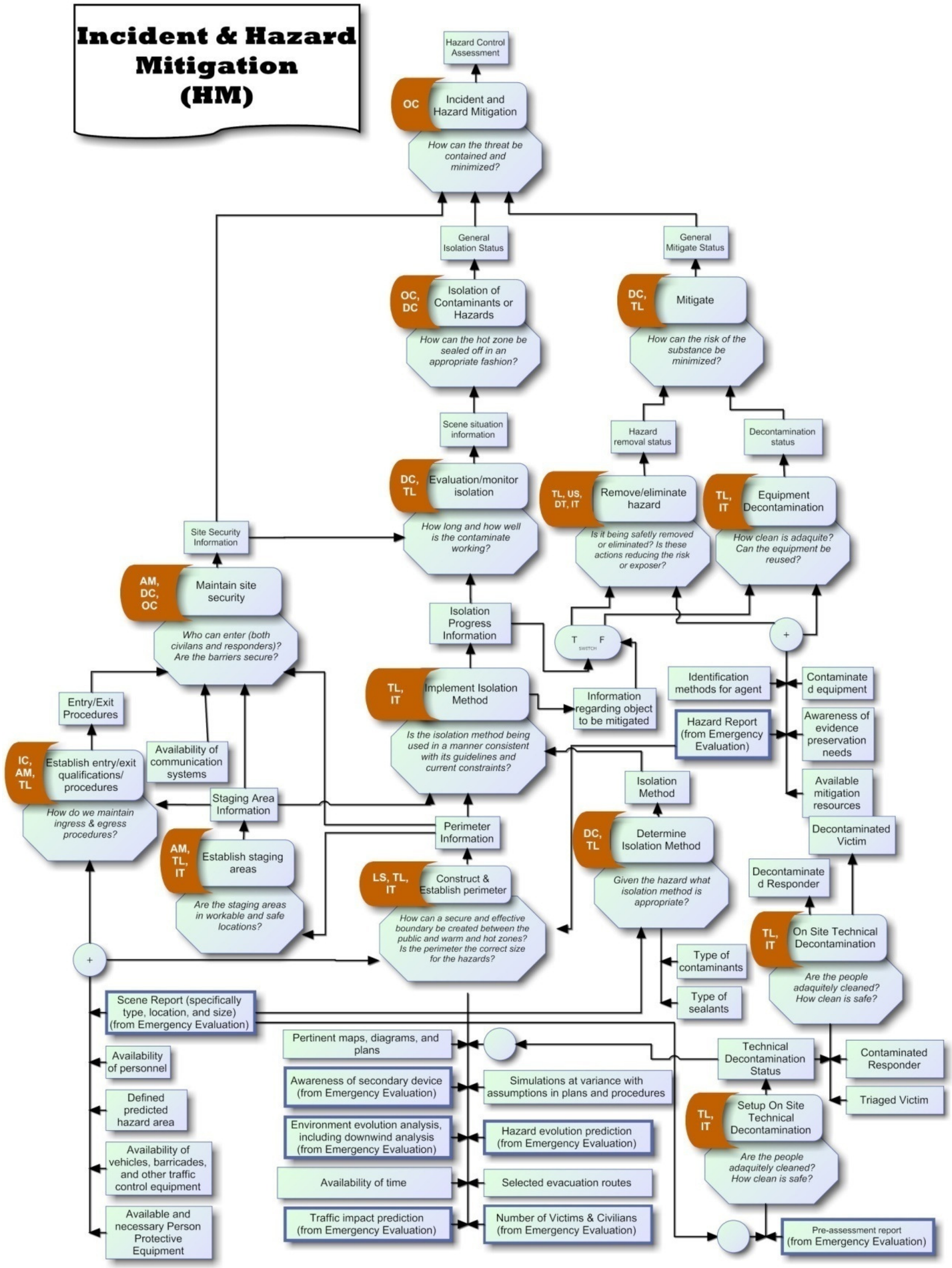


Appendix B.13: CbTA Statecharts: Public Protection

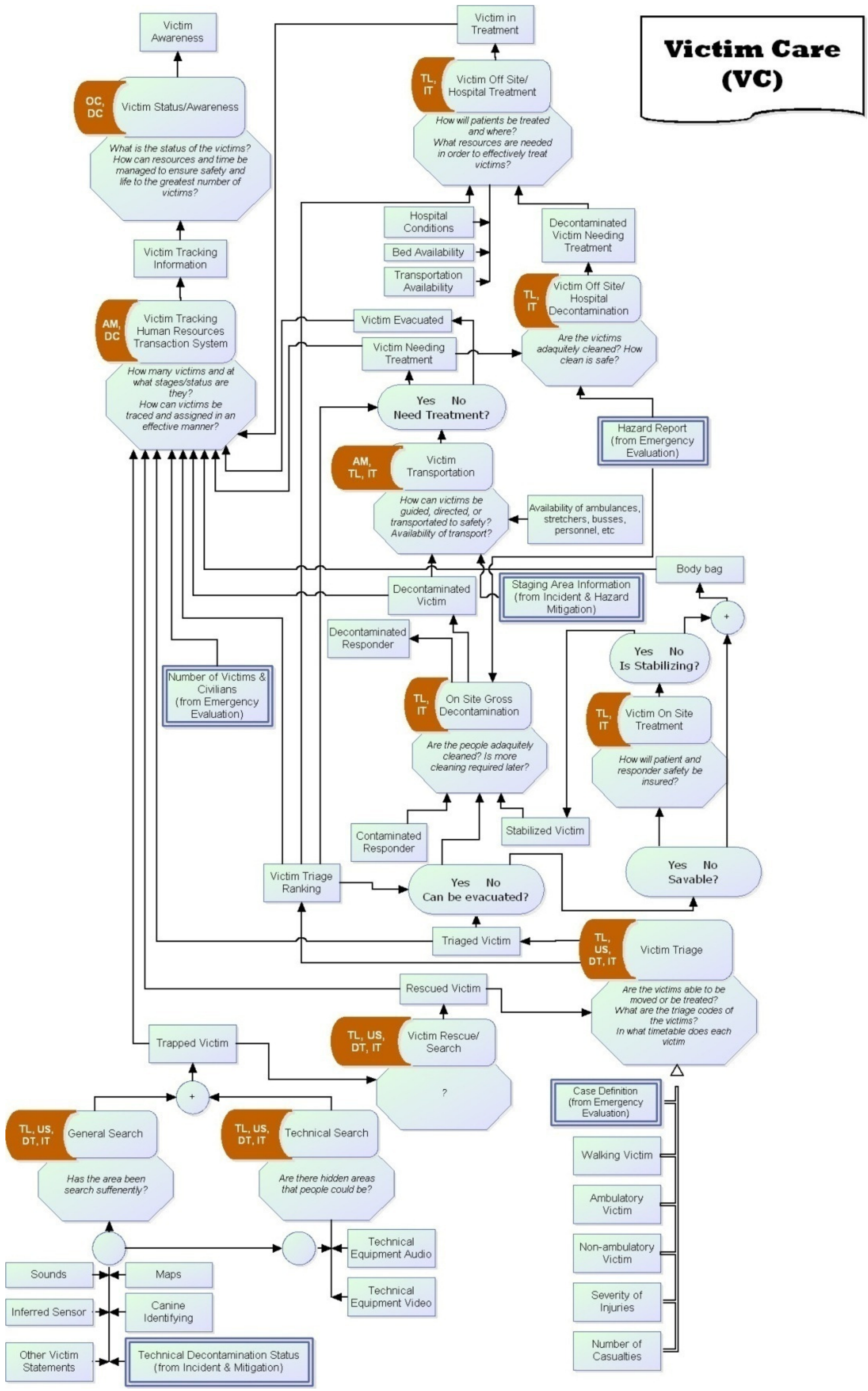
APPENDIX C: THE COMPLETE RESULTS OF THE CIFA.



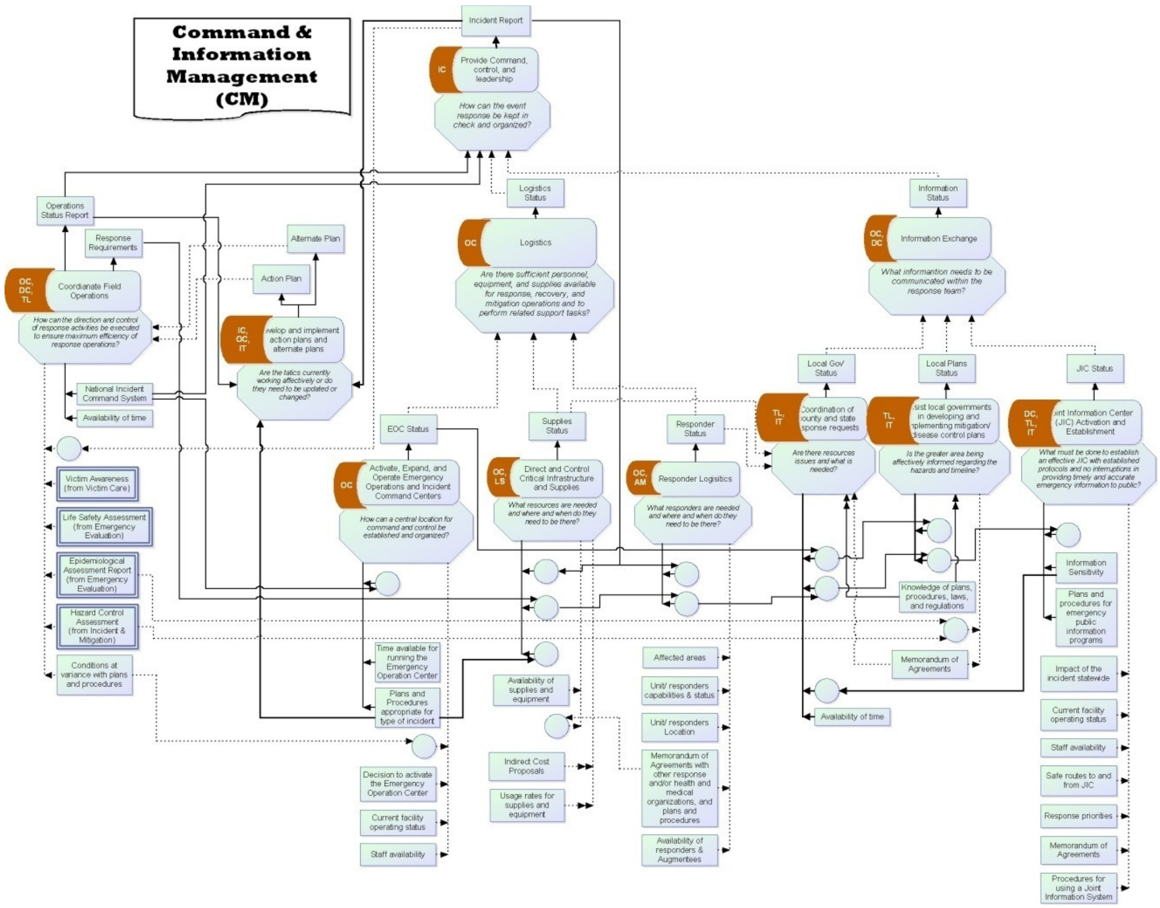
Appendix C.1: CIFA Emergency Evaluation



Appendix C.2: CIFA Incident and Hazard Mitigation



Appendix C.3: CIFA Victim Care



Appendix C.4: CIFA Command and Information Management

APPENDIX D: THE GREATER NASHVILLE EXERCISE WITH ROBOTS.

Format: Event #, overall time (T), biological time (B), explosion time (E), day time, and event description.

01) T: -141:00 B: -141:00 12:00pm

Events: 1 confirmed case of Whopping Cough in Metro Nashville Area

02) T: -123:00 B: -123:00 6:00am

Events: A canister containing a colorless and odorless cocktail of *Francisella tularensis* (Tularemia or Rabbit Fever) and *Yersinia pestis* (Pneumonic Plague) is planted by terrorists in the misting system of an enclosed rabbit farm structure of the Nashville State Fair.

03) T: -95:00 B: -95:00 10:00am

Events: The first patients with signs and symptoms of Pneumonic Plague are beginning to show up at area hospitals and physician offices. Some are admitted, others are sent home with or without antibiotics. Blood cultures, sputum samples are 'collected' from all admitted patients and on only a few of those not admitted by hospital labs.

User Levels / Information Flow:

Note: No higher levels because incident has not started yet.

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Area hospitals and physicians reports
- (0013) Case definition development started
- (0021) Types of symptoms reported

RESULTS:

- (0023) Epidemiological Information

- Victims/ Civilians

04) T: -93:00 B: -93:00 12:00pm

Events: 13 confirmed cases and 87 suspected cases of Whooping Cough reported in the Metro Nashville area.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Area hospitals and physicians reports

o (0012) Started Determining disease transmission pattern
o (0013) Case definition development updated
o (0018) Victim Data regarding cases of Whooping Cough

RESULTS:

o (0017) Number of Victims
o (0023) Epidemiological Information

- Victims/ Civilians

05) T: -71:00 B: -71:00 10:00am

Events: The blood cultures drawn the previous day are flagging 'Positive' at 24-hours on the hospital labs' automated instruments. No organisms are isolated on plates for the hospital labs to view at this point. Routinely, the hospital labs perform Gram Stains and subculturing to plated media to isolate organisms from the blood culture bottle.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

o (0011) Hospital Lab reports
o (0014) Biological Samples

RESULTS:

o None at this point in time

06) T: -70:00 B: -70:00 11:00am

Events: The sputum cultures have now been plated and growing for 24 hours. Photomicrographs with close-ups of a sputum culture plated to Sheep Blood Agar (SBA), Chocolate Agar (CA) and MacConkey Agar (MAC) are provided to hospital labs for diagnosis and comment. At this point, *Y. pestis* colonies will be tiny (but discernable) on MAC, but the colonies SBA and CA will be difficult to discriminate due to overgrowth of faster growing normal respiratory flora. *F. tularensis* will not be recovered.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

o (0011) Hospital Lab reports
o (0014) Biological Samples

RESULTS:

o (0023) Preliminary Epidemiological Information

07) T: -48:00 B: -48:00 9:00am

Events: 42 confirmed cases and 109 suspected of Whooping Cough. There are 16 reported dead from, or with symptoms similar to Whooping Cough. In addition, 219 cases are reported with symptoms similar to Whooping Cough but that have tested negative to Whooping Cough.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports
- (0012) Determining disease transmission pattern
- (0013) Case definition development updated
- (0018) Victim Data regarding cases of Whooping Cough

RESULTS:

- (0017) Number of Victims
- (0021) Types of symptoms reported

- Victims/ Civilians

08) T: -47:00 B: -47:00 10:00 am

Events: The blood culture bottles have been growing for 48 hours; blood cultures have been plated and growing for 24 hours. Subcultures from the positive blood cultures (provided with photomicrographs of close-up views) will demonstrate *Y. pestis* as tiny colonies from which only limited biochemicals and spot tests could be performed.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports
- (0014) Biological Samples

RESULTS:

- (0023) Updated Epidemiological Information

09) T: -46:00 B: -46:00 11:00 am

Events: The sputum cultures have now been plated and growing for 48 hours. Y. pestis should be growing well. The hospital laboratories will indicate on what testing they would perform on the suspicious colonies (e.g., automated identification methods, Oxidase, Catalase, or Urease).

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports
- (0014) Biological Samples

RESULTS:

- (0023) Updated Epidemiological Information

10) T: -45:00B:-45:0012:00 pm **Events:** While raiding what was thought to be a methamphetamine laboratory, Metropolitan Nashville Police Officers discover a homemade biological laboratory containing manuals detailing how to create and dispense *Francisella tularensis* and *Yersinia pestis.*

UV Tasks: detection and decontamination

UV Types: UV-D (Indoor Quadrotor, #1-2), UV-DC (Inmobot, #1)

Improvements: deployment speed, removal of explosion risk from officers due to meth lab setup, early detection, early flagging of possible biological agent's present, reliable decontamination

Events with UVs: While raiding what was thought to be a methamphetamine laboratory using a quick detection UV (UV-D), the UV Specialists discovered what appeared to be a homemade biological laboratory (as indicated by the early detection sensor) containing manuals detailing how to create and dispense *Francisella tularensis* and *Yersinia pestis.* A decontamination system (UV-DC) was deployed to thoroughly decontaminate the Officers from possible exposure to the biological agents.

User Levels / Information Flow:

- Division Chief /Operations Chief (Law Enforcement, HAZMat)

INPUTS:

- (0043) Scene Report
- (0027) Hazard Report

RESULTS:

- (0051) Life Safety Assessment

- Team Leader (HAZMat, Law Enforcement, SWAT)

INPUTS:

- (0025) Hazardous readings

- (0024) Hazardous materials
- (0026) Classification mechanisms
- (0043) Scene Report

RESULTS:

- (0027) Hazard Report

• Human Teammates (HAZMat, Law Enforcement, SWAT, EOC & IC Staff)

INPUTS:

- (0002) Hazard locations
- (0003) Hazard behavior information
- (0006) Hazard detection equipment readings
- (0009) Hazard description information
- (0019) Eye witness accounts from officers
- (0026) Classification mechanisms
- (0039) Out of place (relative to methamphetamine lab) manuals
- (0030) Emergency Management Information System

RESULTS:

- (0042) Out of place item report regarding biological agents discussed in manual
- (0043) Scene Report
- (0027) Hazard Report
- (0025) Hazardous readings
- (0024) Hazardous materials
- (0022) Incident Information

For Detection UV (UV-D):

• UV Specialist (Law Enforcement Member)

INPUTS:

- (0002) Hazard Locations
- (0009) Hazard description information
- (0039) Out of place (relative to methamphetamine lab) manuals

RESULTS:

- (0025) Hazardous readings
- (0024) Hazardous materials

• UV Teammates (Law Enforcement, HAZMat, SWAT)

INPUTS:

- (0002) Hazard Locations
- (0009) Hazard description information
- (0039) Out of place (relative to methamphetamine lab) manuals

RESULTS:

- (0025) Hazardous readings
- (0024) Hazardous materials

- Unmanned Vehicle

INPUTS:

- (0002) Hazard Locations
- (0009) Hazard description information
- (0039) Out of place (relative to methamphetamine lab) manuals

RESULTS:

- (0025) Hazardous readings
- (0024) Hazardous materials samples

For Decontamination UV (UV-DC):

- UV Specialist (HAZMat Team Member) & Unmanned Vehicle

INPUTS:

- (0027) Hazard Type
- (0168) Contaminated Responder

RESULTS:

- (0169) Decontaminated Responder

11) T: -44:00B:-44:001:00 pm **Events:** The Tennessee National Guard's 45th CST (Civil Support Team) activated to collect samples and perform onsite analysis with their rapid identification methods.

UV Tasks: identification, and decontamination

UV Types: UV-I (Ground, #1-2), UV-DC (Inmobot, #1)

Improvements: deployment speed, removal of explosion risk from officers due to meth lab setup, early detection, identification of current agent threat levels and type, reliable decontamination

Events with UVs: The Tennessee National Guard's 45th CST (Civil Support Team) activated to collect samples using identification UV (UV-I) and perform onsite analysis with their rapid identification methods. A decontamination system (UV-DC) was deployed to thoroughly decontaminate the team from possible exposure to the biological agents.

User Levels / Information Flow:

- Operations Chief (Civil Support Team)

INPUTS:

- (0027) Hazard Identification
- (0044) Epidemiological Assessment Report

RESULTS:
- (0051) Life Safety Assessment
- Team Leader (Civil Support Team) & Human Teammates (Civil Support Team)

INPUTS:
- (0023) Update Epidemiological Information
- (0024) Hazardous materials
- (0025) Hazardous readings
- (0026) Classification mechanisms

RESULTS:
- (0027) Hazard Identification
- (0044) Epidemiological Assessment Report

For Identification UV (UV-I):
- UV Specialist & UV Teammates (Civil Support Team)

INPUTS:
- (0010) Hazardous materials samples taken
- (0014) Biological samples taken

RESULTS:
- (0024) Hazardous materials
- (0025) Hazardous readings
- (0023) Update Epidemiological Information
- Unmanned Vehicle

RESULTS:
- (0010) Hazardous materials samples taken
- (0014) Biological samples taken

For Decontamination UV (UV-DC):
- UV Specialist (Civil Support Team Member) & Unmanned Vehicle

INPUTS:
- (0027) Hazard Type
- (0168) Contaminated Responder

RESULTS:
- (0169) Decontaminated Responder

12) T: -40:00 B:- 40:00 5:00 pm

Events: The samples collected by CST are delivered by law enforcement to the Nashville Public Health Lab. The Nashville Public Health Lab's BERT Team uses LRN protocols to screen these samples and discovers bioterror organisms. TDPH contacts the appropriate officials and activates the TN Health Alert Network (THAN) to alert hospitals to be on the watch for the bioterror organisms detected by the BERT Team.

User Levels / Information Flow:

- Division Chief (EOC Staff)

INPUTS:

- (0044) Epidemiological Assessment Report

RESULTS:

- ?

- Team Leader (Civil Support Team)

INPUTS:

- (0023) Updated Epidemiological Information

RESULTS:

- (0044) Epidemiological Assessment Report

- Human Teammates (Public Health)

INPUTS:

- (0014) Biological samples

RESULTS:

- (0023) Updated Epidemiological Information

13) T: -23:00 B: -23:00 10:00 am

Events: The blood culture colonies will be at 48-hours growth at this point. The presence of *F. tularensis* will be faint at best, and only if the culture is void of rapid growing normal respiratory organisms.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports
- (0014) Biological Samples

RESULTS:

- (0023) Updated Epidemiological Information

14) T: -22:00 B: -22:00 11:00 am

Events: The sputum culture colonies will be at 72-ours growth at this point. *Y. pestis* will be growing well.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports

o (0014) Biological Samples

RESULTS:

o (0023) Updated Epidemiological Information

15) T: -21:30 B: -21:30 11:30 am

Events: The hospital laboratory will receive additional input and they will indicate their next course of action regarding the cultures and smears.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

o ?

RESULTS:

o ?

16) T: -19:00 B: -19:00 2:00 pm

Events: Maintenance staff from the Fair Grounds report to local law enforcement that they found a canister device connected to the misting system of the enclosed rabbit farm structure.

User Levels / Information Flow:

- Human Teammates (Law Enforcement)

INPUTS:

o (0019) Eye witness report

o (0020) Reporting to local law enforcement

o (0039) Canister device is an out of place item

RESULTS:

o (0042) Report regarding the out of place item

- Victims/ Civilians

17) T: -17:00 B: -17:00 4:00 pm

Events: The authorities recover the empty canister from the Fair Grounds and transport it to cUV-MAe labs.

User Levels / Information Flow:

- Human Teammates (Law Enforcement)

INPUTS:

o (0010) Possible hazardous materials samples

RESULTS:

o ?

18) T: +00:00 B: +00:00 9:00 am

Events: Local emergency rooms are filling up with patients exhibiting symptoms of *Y. pestis* and *F. tularensis* contamination.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0018) Patient data
- (0012) Patient whereabouts feed into update disease transmission pattern
- (0011) Reports from area emergency rooms

RESULTS:

- (0021) Types of symptoms reported

- Victims/ Civilians

19) T: +00:15 B: +00:15 9:15 am

Events: Public Health and Nashville EOC are faxed a report from Metro Nashville Police concerning the raid in which manuals were found detailing how to create and dispense *Francisella tularensis* and *YeUV-Inia pestis.*

User Levels / Information Flow:

- Incident Commander (EOC)

INPUTS:

- (0051) Life Safety Assessment

RESULTS:

-

- Operations Chief (EOC)

INPUTS:

- (0042) Out of place item report faxed
- (0043) Early Scene report faxed

RESULTS:

- (0051) Life Safety Assessment

- Human Teammates (Law Enforcement)

INPUTS:

- (0030) Emergency Management Information System

RESULTS:

- (0042) Out of place item report faxed
- (0043) Early Scene report faxed

- Victims/ Civilians

20) T: +00:20 B: +00:20 9:20 am

Events: 59 confirmed cases and 176 suspected cases of Whooping Cough, but there are also 424 cases with symptoms similar to Whooping Cough but have tested negative to Whooping Cough. At least 80 of these latter

cases are also exhibiting acute eye (conjunctiva) and throat infections (pharyngeal ulcers).
User Levels / Information Flow:
- Human Teammates (Hospital Staff)

INPUTS:
- (0017) Number of Victims reported
- (0021) Types of symptoms reported
- (0013) Update case definition

RESULTS:
- (0023) Epidemiological Information

- Victims/ Civilians

21) T: +00:30 B: +00:30 9:30 am

Events: Public Health and Nashville EOC are faxed a follow-up message about the empty canister found connected to the misting system of the enclosed rabbit farm structure. The canister had fingerprints of the suspect connected to the *F. tularensis* and *Y. pestis* documents recovered in the raid.
User Levels / Information Flow:
- Incident Commander (EOC)

INPUTS:
- (0051) Life Safety Assessment

RESULTS:
-

- Operations Chief (EOC, Public Health)

INPUTS:
- (0042) Out of place item report faxed
- (0043) Early Scene report faxed

RESULTS:
- (0051) Life Safety Assessment

- Human Teammates (Law Enforcement)

INPUTS:
- (0030) Emergency Management Information System

RESULTS:
- (0042) Out of place item report
- (0043) Fairground scene report

- Victims/ Civilians

22) T: +00:35 B: +00:35 9:35 am

Events: The EOC is activated.
User Levels / Information Flow:
- Operations Chief (EOC)

INPUTS:
- (0133) EOC status

RESULTS:

- (0144) Logistics Status

23) T: +00:40 B: +00:40 9:40 am

Events: Patients not exposed to the biological agents released at the State Fair are showing visible signs of *Y. pestis* (these represent the secondary or person-to-person transmission cases). There are 62 reported dead from or with symptoms similar to Whooping Cough.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:

- (0011) Hospital Lab reports
- (0012) Patient whereabouts feed into update disease transmission pattern
- (0021) Types of symptoms reported

RESULTS:

- (0023) Updated Epidemiological Information

- Victims/ Civilians

24) T: +00:45 B: +00:45 9:45 am

Events: Public Health notifies hospitals to possibility of biological contaminator and requests status possible *Y. pestis* and *F. tularensis* symptoms by patient.

User Levels / Information Flow:

- Team Leader (Public Health)

INPUTS:

- (0023) Epidemiological Information shared

RESULTS:

- (0027) Update Hazard Report

- Human Teammates (Hospital Staff)

INPUTS:

- (0013) Update case definition
- (0011) Hospital Lab reports
- (0021) Types of symptoms reported

RESULTS:

- (0023) Epidemiological Information shared

- Victims/ Civilians

25) T: +02:00 B: +02:00 11:00 am

Events: Hospital labs will report their final diagnosis.

User Levels / Information Flow:

- Team Leader (Hospital Labs) & Human Teammates (Hospital Labs)

INPUTS:
○ ?
RESULTS:
○ (0044) Epidemiological Assessment Report

26) T: +02:15 B: +02:15 11:15 am

Events: The media reports an outbreak of *Y. pestis* occurring in the Nashville area.

27) T: +02:30 B: +02:30 11:30 am

Events: State Labs confirm presence of *F. tularensis* and *Y. pestis* to hospital labs. The State epidemiologists are contacted with the results of findings.

User Levels / Information Flow:

- Team Leader (State Lab)

INPUTS:
○ (0023) Epidemiological Information shared
RESULTS:
○ (0044) Epidemiological Assessment Report

- Human Teammates (State Lab)

INPUTS:
○ (0021) Types of symptoms reported
RESULTS:
○ (0023) Epidemiological Information shared
○ (0044) Epidemiological Assessment Report

28) T: +03:00 B: +03:00 12:00 pm

Events: Hospitals start reporting to Public Health numbers of confirmed *Y. pestis* and *F. tularensis* and available beds.

User Levels / Information Flow:

- Human Teammates (Hospital Staff)

INPUTS:
○ (0011) Hospital Lab reports
○ (0017) Number of Victims reported
RESULTS:
○ (0023) Updated Epidemiological Information

- Victims/ Civilians

29) T: +04:00 E: +00:00 1:00 pm

Events: TN Tower (State Building) explodes.

30) T: +04:01 E: +00:01 1:01 pm

Events: Multiple 911 calls are received in the Emergency Communications Center (ECC) reporting explosions at the TN Tower building. Some calls report that the TN Tower was bombed.

User Levels / Information Flow:

- Human Teammates (911 Call Centers)

INPUTS:

- (0019) Eye witness accounts
- (0020) 911 Calls

RESULTS:

- (0022) Incident Information

- Victims/ Civilians

31) T: +04:03 E: +00:03 1:03 pm

Events: Building security personnel are reporting massive amounts of casualties and fatalities on scene.

User Levels / Information Flow:

- Human Teammates (911 Call Centers)

INPUTS:

- (0019) Eye witness accounts
- (0020) 911 Calls
- (0018) Victim data

RESULTS:

- (0017) Number of Victims
- (0022) Incident Information

- Victims/ Civilians

32) T: +04:05 E: +00:05 1:05 pm

Events: First Responders begin to arrive at the scene and report there has been an explosion at the TN Tower. The west side of the TN Tower has been torn off and has collapsed into the building about 150 feet wide and 100 feet into the building and upwards of approximately 300 feet. Several small fires and a damaged portion of the TN Tower have been reported. People are walking around dazed, confused, and bleeding. There are bodies and body parts visible lying on the ground. The debris in the street is slowing down responders.

UV Tasks: detection, identification, medical initial assessment, victim transportation, scene tracking, resource hauling, and decontamination

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-MA (Small Ground, #1+), UV-VT (Ground, #1+), UV-ST (Blimp, #1+), UV-DC (Inmobot, #1-2), & UV-RH (Ground, #1+)

Improvements: deployment speed, reduction of explosion risk to officers due to meth lab setup, early detection, identification of current agent threat levels and type, reliable decontamination

Events with UVs: First Responders begin to arrive at the scene and immediately deploy detection (UV-D), identification (UV-I), and scene tracking UV (UV-ST) and report there has been an explosion at the TN Tower. Using the UV-D the responders report that the west side of the TN Tower has been torn off and has collapsed into the building about 150 feet wide and 100 feet into the building and upwards of approximately 300 feet and that several small fires and a damaged portion of the TN Tower have been reported. The UV-ST indicates that People are walking around dazed, confused, and bleeding. Those victims are being assessed using the medical initial assessment UV (UV-MA) and those that can be transported away are starting to be moved away via the medical victim transportation UV (UV-VT). There are bodies and body parts visible lying on the ground. The debris in the street is slowing down responders; however, they are using their resource hauling UV (UV-RH) to help them carry their equipment around the debris. A decontamination system (UV-DC) is being deployed to thoroughly decontaminate the team from possible exposure to harmful agents.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:

- (0051) Life Safety Assessment
- (0125) Victim Awareness

RESULTS:

- (0129) Operations Status Report
- (0130) Response Requirements
- (0145) Incident Report

- Division Chief /Operations Chief (Law Enforcement, HAZMat, Fire, EMS)

INPUTS:

- (0043) Scene Report
- (0027) Hazard Report

RESULTS:

- (0051) Life Safety Assessment

- (0125) Victim Awareness

For Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0040) Meteorological Reports
- (0030) Emergency Management Information System

RESULTS:

- (0035) Augmented Maps
- (0062) Location of Event
- (0052) Number of People
- (0058) Type of situation
- (0063) Type of event
- (0049) Defined predicted hazard
- (0043) Scene Report

For Medical Initial Assessment (UV-MA)

- Team Leader (EMS) UV Specialist (EMS), UV Teammates (EMS), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0104) Walking Victims
- (0106) Non-ambulatory Victims
- (0107) Severity of injuries
- (0108) Number of causalities
- (0103) Rescued Victims
- (0102) Trapped Victims

RESULTS:

- (0018) Victim data
- (0109) Triaged Victims

For Detection UV (UV-D) & Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0002) Hazard Locations and dispersion

- (0008) Hazard detection equipment readings
- (0009) Hazard description information
- (0001) Toxic industrial chemical detection readings
- (0007) Radiation Meters
- (0005) Images (photo and video)
- (0006) Air monitoring devices
- (0004) Background Radiation Levels
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0026) Classification mechanisms
- (0030) Emergency Management Information System
- (0091) Inferred Sensors
- (0090) Sounds from ruble
- (0093) Canine Identifying
- (0097) Technical Equipment video
- (0101) Technical Equipment audio

RESULTS:

- (0018) Victim data
- (0027) Present Hazard Report
- (0034) Structural Reports
- (0035) Augmented Maps
- (0058) Type of situation
- (0063) Type of event
- (0049) Defined predicted hazard
- (0043) Scene Report
- (0102) Trapped Victims

For Medical Victim Transportation UV (UV-VT):

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0115) Victim needing transportation
- (0114) Scene procedures
- (0035) Augmented Maps

RESULTS:

- (0117) Victim needing treatment

For Decontamination UV (UV-DC):

- UV Specialist (HAZMat) & Unmanned Vehicle

INPUTS:

- (0027) Hazard Type

o (0168) Contaminated Responder

RESULTS:

o (0169) Decontaminated Responder

33) T: +04:06 E: +00:06 1:06 pm

Events: TV news crews arrive on the scene and broadcast pictures of the scene nationwide. They report there is a bombing of the TN Tower and live feed goes out showing walking victims, bodies, and body parts on the ground.

User Levels / Information Flow:

- Human Teammates (EOC Staff)

INPUTS:

o (0005) Video

o (0019) Eye witness accounts

o (0018) Victim data

RESULTS:

o ?

- Victims/ Civilians

34) T: +04:07 E: +00:07 1:07 pm

Events: The ECC's Field Incident Response Situation Team (FIRST) deploys to the scene and takes over all tasks normally handled within the center, including notifications and requests for additional resources. The ECC begins to backfill fire halls and perform medical move ups to provide coverage for the remainder of the City. The MCI plan is activated and notifications are made.

User Levels / Information Flow:

- Incident Commander (EOC), Division Chiefs (various), Team Leaders (various)

INPUTS:

o

RESULTS:

o (0130) Response Needs

35) T: +04:08 E: +00:08 1:08 pm

Events: Additional First responders arrive on scene to find many Good Samaritans are on the collapsed structure trying to help. Good Samaritans are knocking over debris and falling down while walking and shifting the debris.

UV Tasks: detection

UV Types: UV-D (Outdoor Quadrotor, #1+)

Improvements: removal of risk from Good Samaritans, better scene preservation

Events with UVs: Additional First responders arrive on scene to find many Good Samaritans are on the collapsed structure trying to help. They instruct the Good Samaritans to limit damaging the debris and deploy the UV-D to recon into the area preventing more Good Samaritans from getting hurt.

User Levels / Information Flow:

- Division Chief /Operations Chief (Law Enforcement, HAZMat, Law Enforcement, EMS)

INPUTS:

- (0043) Scene Report
- (0052) Number of people

RESULTS:

- (0051) Life Safety Assessment
- (0125) Victim Awareness

For Detection UV (UV-D)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0018) Victim data

RESULTS:

- (0034) Structural Reports
- (0035) Augmented Maps
- (0043) Scene Report
- (0017) Number of Victims

- Victims/ Civilians

36) T: +04:09 E: +00:09 1:09 pm

Events: Law enforcement begins securing the area and establishing a security perimeter.

UV Tasks: scene tracking

UV Types: UV-ST (Blimp, #1+)

Improvements: Asserting quality of containment both for agents and from humans

Events with UVs: Law enforcement beings securing the area and establish a security perimeter with the UV-ST deployed to ascertain the quality of the perimeter for both agents and humans.

User Levels / Information Flow:

For Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:

- (0067) Availability of personnel

RESULTS:

- (0067) Availability of personnel

37) T: +04:10 E: +00:10 1:10 pm

Events: Fire, Police, and OEM mobile command vehicles have arrived and are establishing communication capabilities with each other.

User Levels / Information Flow:

- Operations Chief (EOC)

INPUTS:

- (0151) Responder Status

RESULTS:

- (0144) Logistics Status

- Operations Chief (EOC) & Staging Area Manager (EOC)

INPUTS:

- (0147) Responders capabilities
- (0146) Responders locations

RESULTS:

- (151) Responder Status

38) T: +04:11 E: +00:11 1:11 pm

Events: The smell of natural gas is detected. Fire mains are broken and there is no power in downtown Nashville.

UV Tasks: detection, identification

UV Types: UV-D (Quadrotor, #1+) & UV-I (Quadrotor, Ground, or Blimp, #1+)

Improvements: early detection, identification of current agent threat levels and type

Events: The smell of natural gas is detected by the UV-D and identified by the UV-I. Fire mains are broken and there is no power in downtown Nashville.

For Detection UV (UV-D) & Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0033) Sensors
- (0001) Chemical detection readings

RESULTS:
- o (0025) Hazardous readings
- o (0027) Present Hazard Report
- o (0035) Augmented Maps
- o (0038) Awareness of secondary devices
- o (0043) Scene Report

39) T: +04:12 E: +00:12 1:12 pm

Events: Unified Command is established.

40) T: +04:13 E: +00:13 1:13 pm

Events: Many family members and concerned citizens begin to arrive in the attempt to locate their family members and friends.

UV Tasks: scene tracking

UV Types: UV-ST (Blimp, #1+)

Improvements: Early identification of citizen gathering points.

Events with UVs: Many family members and concerned citizens begin to arrive in the attempt to locate their family members and friends and are referred to the DSS with update results regarding victim tracking. The UV-ST identifies citizen-gathering areas to help responders better direct citizens towards the DSS and away from dangerous areas.

Decision Support System: Results from triage and victim tracking (and possibly UV-MA, UV-VT, & UV-DC) could be relayed to families

User Levels / Information Flow:

For Scene/Object Tracking (UV-ST)

- UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:
- o ?

RESULTS:
- o (0012) Number of people

41) T: +04:14 E: +00:14 1:14 pm

Events: Fire and EMS establish on-site triage and treatment.

UV Tasks: Medical Initial Assessment

UV Types: UV-MA (Small Ground, #1+)

Improvements: reliable decontamination with quality assurances

Events with UVs: Fire and EMS establish on-site triage and use the UV-DC for in field triage.

- Division Chief /Operations Chief (Fire, EMS, EOC)

INPUTS:
- (0109) Triaged Victims
- (0114) Stabilized Victims
- (0110) Victim Triage Rankings

RESULTS:
- (0124) Victim Tracking Information
- (0125) Victim Awareness

- Team Leader (EMS) & Human Teammates (EMS), Area Manager (EOC)

INPUTS:
- (0112) Triaged Victims
- (0110) Victim Triage Rankings

RESULTS:
- (0114) Stabilized Victims
- (0124) Victim Awareness

For Medical Initial Assessment (UV-MA)
- Team Leader (Fire, EMS), UV Specialist (Fire, EMS), UV Teammates (Fire, EMS), & Unmanned Vehicle

INPUTS:
- (0106) Non-ambulatory Victims
- (0105) Ambulatory Victims
- (0107) Severity of injuries
- (0108) Number of causalities
- (0103) Rescued Victims

RESULTS:
- (0109) Triaged Victims
- (0110) Victim Triage Rankings

42) T: +04:15 E: +00:15 1:15 pm

Events: A local reporter overhears a conversation between two police officers saying that the explosion looks intentional. National news reports soon begin to air with titles of “TN Tower Bombed”, “America Attacked Again”, and “The Bombing of Nashville.”

43) T: +04:16 E: +00:16 1:16 pm

Events: TEMA is notified of the incident and activates its EOC.

User Levels / Information Flow:
- Team Leader (EOC) & Human Teammates (EOC)

INPUTS:
- ?

RESULTS:
- (0155) Local Government Status

44) T: +04:17 E: +00:17 1:17 pm

Events: ATF and FBI are notified of the explosion.

User Levels / Information Flow:

- Team Leader (EOC) & Human Teammates (EOC)

INPUTS:

- ?

RESULTS:

- (0155) Local Government Status

45) T: +04:21 E: +00:21 1:21 pm

Events: Highway patrol begins rerouting traffic to prevent it from entering the downtown area.

User Levels / Information Flow:

- Team Leader (Highway Patrol) & Human Teammates (Highway Patrol)

INPUTS:

- (0047) Traffic Impact Prediction

RESULTS:

- ?

46) T: +04:25 E: +00:25 1:25 pm

Events: The First victims start arriving at local hospitals

User Levels / Information Flow:

- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:

- (0123) Victim in Treatment
- (0124) Victim Tracking Information

RESULTS:

- (0125) Victim Awareness

- Team Leader (Hospital Staff) & Human Teammates (Hospital Staff)

INPUTS:

- (0122) Victims needing Treatment
- (0121) Hospital Conditions
- (0120) Bed Availability
- (0119) Transportation Availability

RESULTS:

- (0123) Victim in Treatment

- Victims/ Civilians

47) T: +04:28 E: +00:28 1:28 pm

Events: The Medical Examiner is directed to report to the TN Tower due to the large number of victims who are deceased.

User Levels / Information Flow:

- Human Teammates (Medical Examiner)

INPUTS:

○ (0113) Victims in body bags

RESULTS:

○ ?

- Victims/ Civilians

48) T: +04:30 E: +00:30 1:30 pm

Events: Several of the concerned family members and citizens become hysterical to the point that they begin to interfere with response operations.

User Levels / Information Flow:

- Human Teammates (Law Enforcement)

INPUTS:

○ (0082) Site Security Information

RESULTS:

○ ?

- Victims/ Civilians

49) T: +04:30 E: +00:30 1:30 pm

Events: The Mayor of Nashville declares a local state of emergency and requests a state level declaration of emergency.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:

○ (0156) Information Status

RESULTS:

○ ?

50) T: +04:35 E: +00:35 1:35 pm

Events: All utilities have been shut down in the immediate downtown area.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

○ (0043) Scene Report

RESULTS:

○ (0051) Life Safety Assessment

51) T: +04:40 E: +00:40 1:40 pm

Events: Evacuation and shelter-in-place radius is established by local law enforcement.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+),

Improvements: assist in identifying agent dispersion patterns.

Events with UVs: Evacuation and shelter-in-place radius is established based on information gathered on the agent's dispersion pattern from the UV-D, UV-I, and UV-ST. The information is disseminated to the populous via the local law enforcement.

User Levels / Information Flow:

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement, HAZMat), UV Specialist (Law Enforcement, HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- o (0032) Maps
- o (0009) Hazard description information
- o (0016) Pre-assessment report
- o (0030) Emergency Management Information System

RESULTS:

- o (0049) Downwind hazard analysis
- o (0043) Scene Report

52) T: +04:45 E: +00:45 1:45 pm

Events: The local Urban Search and Rescue Team arrives and begins assisting Nashville Fire Department operations.

Use: USAR robots

Outside scope.

53) T: +04:45 E: +00:45 1:45 pm

Events: The Governor declares a statewide emergency.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- o (0155) Local Government Status

RESULTS:

- o (0156) Information Status

54) T: +04:45 B: +4:45 1:45 pm **Events:** Nashville Public Health officials in conjunction with surrounding counties declare the situation a public health emergency.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- (0155) Local Government Status

RESULTS:

- (0156) Information Status

55) T: +04:53 E: +00:53 1:52 pm

Events: FBI and ATF arrive on scene and establish a Joint Operations Center.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- (0158) JIC Status

RESULTS:

- (0156) Information Status

- Team Leader (FBI, ATF) & Human Teammates (FBI, ATF)

INPUTS:

- (0159) Impact of the incident statewide
- (0160) Current facility operation status
- (0161) Staff availability
- (0162) Information Sensitivity
- (0163) Safe routes to and from JIC
- (0164) Response priorities
- (0165) Plans and procedures for emergency public information programs
- (0166) Memorandum of Agreements
- (0167) Procedures for using a Joint Information System
- (0130) Response Requirements

RESULTS:

- (0158) JIC Status

56) T: +04:55 E: +00:55 1:55 pm

Events: National news reports begin to air stating that the number of fatalities is unknown and the number of injured or missing is upwards of 600.

57) T: +04:57 E: +00:57 1:57 pm

Events: Additional media arrive on scene. A Joint Information Center is established to begin addressing incident related media questions.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- (0158) Joint Information Center status

RESULTS:

- (0156) Information Status

58) T: +05:00 E: +01:00 2:00 pm

Events: A secondary device is detonated (unless it is located and disarmed beforehand by authorities).

UV Tasks: detection

UV Types: UV-D (Quadrotor, #1+)

Improvements: deployment speed, improved coverage area, and early detection

Events with UVs: A secondary device is located by the UV-D and is defused by the Nashville Bomb Squad.

User Levels / Information Flow:

For Detection UV (UV-D)

- Team Leader (Law Enforcement, Bomb Squad), UV Specialist (Law Enforcement, Bomb Squad), UV Teammates (Law Enforcement, Bomb Squad), & Unmanned Vehicle

INPUTS:

- (0030) Emergency Management Information System

RESULTS:

- (0038) Awareness of secondary devices
- (0043) Scene Report

59) T: +05:00 B: +05:00 2:00 pm

Events: Public Health receives at least 160 confirmations on *F. tularensis* and 264 confirmations on *Y. pestis*, and 59 confirmations on Whooping Cough. Public Health contacts the State epidemiologist to request the SNS.

User Levels / Information Flow:

- Human Teammates (Hospital Staff & Public Health)

INPUTS:

- (0011) Results from Hospitals
- (0017) Number of Victims reported

RESULTS:

- (0023) Updated Epidemiological Information

- Victims/ Civilians

60) T: +05:02 E: +01:02 2:02 pm

Events: No hazardous material is detected in or around the explosion area, although HAZMAT teams remain on standby.

UV Tasks: detection

UV Types: UV-D (Quadrotor, #1+)

Improvements: deployment speed, improved coverage area, and early detection
Events with UVs: No hazardous material is detected in or around the explosion area using both the UV-D and by the HAZMAT team personal, although HAZMAT teams remain on standby.
User Levels / Information Flow:
For Detection UV (UV-D) & Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:
- (0025) Hazardous reading
- (0026) Classification mechanisms

RESULTS:
- (0027) Hazard report

61) T: +05:04 E: +01:04 2:04 pm
Events: Red Cross is notified and mass care initiated.

62) T: +05:05 E: +01:05 2:05 pm
Events: Civil Air Patrol does fly over for live feedback to EOC.
UV Tasks: scene tracking
UV Types: UV-ST (Blimp, #1+)
Improvements: deployment speed, scene stability, close (zoom-in'ed) imagery
Events with UVs: The UV-ST provides live feed for the EOC of the scene and provides angles not attainable by the Civil Air Patrol fly over.
User Levels / Information Flow:
For Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:
- (0030) Emergency Management Information System

RESULTS:
- (0031) Imagery
- (0034) Structural Reports
- (0035) Augmented Maps
- (0043) Scene Report

63) T: +05:30 E: +01:30 2:30 pm
Events: A tertiary explosive device is

detonated (unless it is located and disarmed beforehand by authorities).
UV Tasks: detection
UV Types: UV-D (Quadrotor, #1+)
Improvements: deployment speed, improved coverage area, and early detection
Events with UVs: A third device is located by the UV-D and is defused by the Nashville Bomb Squad.
User Levels / Information Flow:
For Detection UV (UV-D)

- Team Leader (Law Enforcement, Bomb Squad), UV Specialist (Law Enforcement, Bomb Squad), UV Teammates (Law Enforcement, Bomb Squad), & Unmanned Vehicle

INPUTS:
- (0030) Emergency Management Information System

RESULTS:
- (0038) Awareness of secondary devices
- (0043) Scene Report

64) T: +05:31 E: +01:31 2:31 pm
Events: Some of the "walking wounded" have self-evacuated to local area hospitals.
UV Tasks: decontamination
Improvements: reliable decontamination with quality assurances
Events with UVs: Some of the "walking wounded" have self-evacuated to local area hospitals are decontaminated via the UV-DC.
For Decontamination UV (UV-DC):

- UV Specialist (HAZMat, Hospital Staff) & Unmanned Vehicle

INPUTS:
- (0027) Hazard Type
- (0168) Contaminated Responder & Victims

RESULTS:
- (0169) Decontaminated Responder & Victims

65) T: +05:49 E: +01:49 2:49 pm
Events: A roadblock radius is established that is six blocks in size.
User Levels / Information Flow:

- Operational Chief & Division Chief (Law Enforcement)

INPUTS:
- (0082) Site Security Information

RESULTS:
- (0088) General Perimeter Status

- Staging Area Manager (EOC), Team Leader (Law Enforcement), & Human Teammates (Law Enforcement)

INPUTS:
- (0068) Perimeter Information
- (0072) Staging Area Information

RESULTS:
- (0074) Entry/Exit Procedures
- (0082) Site Security Information

- Logistics Technical Specialist (EOC), Team Leader (Law Enforcement), & Human Teammates (Law Enforcement)

INPUTS:
- (0063) Type of event
- (0065) Availability of barricades
- (0049) Defined predicted hazard area
- (0057) Availability of time
- (0062) Location of event
- (0061) Size of event
- (0060) Weather and environmental conditions
- (0056) City maps
- (0055) Wind direction and speed
- (0059) Contingency plans and procedures
- (0064) Available of person protective equipment

RESULTS:
- (0068) Perimeter Information

66) T: +05:54 E: +01:54 2:54 pm

Events: Thousands of people in the vicinity are evacuating.

User Levels / Information Flow:
- Victims/ Civilians

67) T: +06:00 B: +06:00 3:00 pm

Events: Public Health and hospitals identify locations for dispensing stations for distribution of antibiotics and identify the targeted recipients.

User Levels / Information Flow:
- Human Teammates
- Victims/ Civilians

68) T: +06:00 C: +00:00 3:00 pm

Events: Train Derailment.

69) T: +06:03 C: +00:03 3:03 pm

Events: Multiple 911 calls are received at the Emergency Communications Center (ECC) from individuals in the vicinity. Fire/EMS units are dispatched to the area.

User Levels / Information Flow:

- Human Teammates (Law Enforcement)

INPUTS:

- o (0019) Eye witness accounts
- o (0020) 911 Calls

RESULTS:

- o (0022) Incident Information

- Victims/ Civilians

70) T: +06:05 E: +02:05 3:05 pm

Events: The Governor of Tennessee and the Mayor of Nashville hold a joint news conference to announce that a Presidential Declaration has been made declaring the explosion an Incident of National Significance.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:

- o (0156) Information Status

RESULTS:

- o

71) T: +06:06 C: +00:06 3:06 pm

Events: Fire/EMS arrives on scene and report a chemical spilling from several tanker cars within the derailment area. Vapors from spilling chemicals are spreading along the ground before dissipating into the air. A request is placed for additional assistance to manage the volume of victims.

UV Tasks: detection, identification, medical initial assessment, victim transportation, scene tracking, resource hauling, and decontamination

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-MA (Small Ground, #1+), UV-VT (Ground, #1+), UV-ST (Blimp, #1+), UV-DC (Inmobot, #1-2), & UV-RH (Ground, #1+)

Improvements: deployment speed, removal of chemical risk from responders, early detection, identification of current agent threat levels and type, reliable decontamination

Events with UVs: Fire/EMS begin to arrive at the scene and imminently deploy detection (UV-D), identification (UV-I), and scene tracking UV (UV-ST) and report a chemical spilling from several tanker cars within the derailment area. The UV-D discover chemicals spreading along the ground and with confirmation from UV-ST notice that the vapors from the chemicals are dissipating into the air. The UV-I begins to attempt to identify the chemical. A request is placed for additional assistance to manage the volume of patients identified by the UV-ST. Those victims are being assessed using the medical initial assessment UV (UV-MA) and those that can be transported away are starting to be moved away via the medical victim transportation UV (UV-VT). Since the responders must stage far away from the chemicals they employ their resource hauling UV (UV-RH) to help them carry their equipment into the hazard zone. A decontamination system (UV-DC) is being deployed to decontaminate thoroughly the team from possible exposure to harmful agents.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:

- (0051) Life Safety Assessment
- (0125) Victim Awareness

RESULTS:

- (0129) Operations Status Report
- (0130) Response Requirements
- (0145) Incident Report

- Division Chief /Operations Chief (Law Enforcement, HAZMat, Fire, EMS, EOC)

INPUTS:

- (0043) Scene Report
- (0027) Hazard Report
- (0124) Victim Awareness

RESULTS:

- (0051) Life Safety Assessment
- (0125) Victim Awareness

- Team Leader (EMS) & Human Teammates (EMS), Area Manager (EOC)

INPUTS:

- (0112) Triaged Victims

- (0110) Victim Triage Rankings

RESULTS:

- (0114) Stabilized Victims
- (0124) Victim Awareness

For Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report

RESULTS:

- (0035) Augmented Maps
- (0062) Location of Event
- (0052) Number of People
- (0058) Type of situation
- (0063) Type of event
- (0049) Defined predicted hazard
- (0043) Scene Report

For Medical Initial Assessment (UV-MA)

- Team Leader (EMS) UV Specialist (EMS), UV Teammates (EMS), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0106) Non-ambulatory Victims
- (0107) Severity of injuries
- (0108) Number of causalities
- (0103) Rescued Victims
- (0104) Walking Victims
- (0102) Trapped Victims

RESULTS:

- (0018) Victim data
- (0109) Triaged Victims

For Detection UV (UV-D) & Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0001) Chemical detection reading

- (0026) Classification mechanisms
- (0008) Hazard detection equipment readings
- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report

RESULTS:

- (0018) Victim data
- (0027) Present Hazard Report
- (0034) Structural Reports
- (0035) Augmented Maps
- (0058) Type of situation
- (0063) Type of event
- (0049) Defined predicted hazard
- (0043) Scene Report

For Medical Victim Transportation UV (UV-VT):

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0115) Victim needing transportation
- (0114) Scene procedures
- (0035) Augmented Maps

RESULTS:

- (0117) Victim needing treatment

For Decontamination UV (UV-DC):

- UV Specialist (HAZMat) & Unmanned Vehicle

INPUTS:

- (0027) Hazard Type
- (0168) Contaminated Responder

RESULTS:

- (0169) Decontaminated Responder

72) T: +06:09 C: +00:09 3:09 pm

Events: Several First responders report feeling dizzy.

User Levels / Information Flow:

- Division Chief (various)

INPUTS:

- (0027) Hazard report

RESULTS:

- (0050) Identify possible protective actions

- Team Leaders (various) & Human Teammates (various)

INPUTS:

- (0021) Types of symptoms
- (0022) Incident Information

RESULTS:

- (0027) Hazard report

73) T: +06:10 C: +00:10 3:10 pm

Events: Several citizens in the area report feeling ill.

UV Tasks: detection, identification, victim transportation, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-VT (Ground, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns and levels, safe removal of people from hazard zone

Events with UVs: Responders do not report feeling dizzy as the UV-D, UV-I, and UV-ST discovered, identified, and tracked the areas affected by the chemical spill. Citizens feeling ill are transported away via the UV-VT.

User Levels / Information Flow:

For Detection UV (UV-D) & Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0003) Hazard behavior information
- (0006) Air monitoring devices

RESULTS:

- (0021) Types of symptoms
- (0022) Incident Information
- (0027) Hazard report
- (0050) Identify possible protective actions
- (0002) Hazard dispersion

For Scene/Object Tracking (UV-ST)

- UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:

- (0030) Emergency Management Information System

RESULTS:
- (0002) Hazard dispersion
- (0043) Scene Report

For Medical Victim Transportation UV (UV-VT):

- UV Specialist (EMS), UV Teammates (EMS), & Unmanned Vehicle

INPUTS:
- (0115) Victim needing transportation
- (0114) Scene procedures
- (0035) Augmented Maps

RESULTS:
- (0117) Victim needing treatment

74) T: +06:10 E: +02:10 3:10 pm The President of the United States, with a Senator from Tennessee in attendance, makes a statement regarding the explosion.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:
- (0156) Information Status

RESULTS:
-

75) T: +06:12 C: +00:12 3:12 pm

Events: Fire/EMS establishes Incident Command and begins triaging patients.

Use: UV-MA, UV-DC

UV Tasks: medical initial assessment and decontamination

UV Types: UV-MA (Small Ground, #1+), UV-DC (Inmobot, #1-2)

Improvements: quicker triage and reliable decontamination

Events with UVs: The Fire/EMS establishes Incident Command and being using the UV-MA and personal to triage patients. A decontamination system (UV-DC) is being deployed to decontaminate thoroughly the patients from possible exposure to harmful agents.

User Levels / Information Flow:

For Medical Initial Assessment (UV-MA)

- Team Leader (EMS), UV Specialist (EMS), UV Teammates (EMS), & Unmanned Vehicle

INPUTS:
- (0032) Maps

- (0009) Hazard description information
- (0019) Eye witness accounts
- (0016) Pre-assessment report
- (0104) Walking Victims
- (0106) Non-ambulatory Victims
- (0107) Severity of injuries
- (0108) Number of causalities
- (0103) Rescued Victims
- (0102) Trapped Victims

RESULTS:

- (0018) Victim data
- (0109) Triaged Victims
- (0110) Victim triage rankings

76) T: +06:14 C: +00:14 3:14 pm

Events: Hospitals are notified of the chemical spills and the need for possible decontamination. Hospitals follow their designated procedures to prepare.

UV Tasks: decontamination

UV Types: UV-DC (Inmobot, #1-2)

Improvements: reliable decontamination with quality assurances

Events with UVs: A decontamination system (UV-DC) is being deployed to decontaminate thoroughly the patients from possible exposure to harmful agents

User Levels / Information Flow:

For Decontamination UV (UV-DC):

- UV Specialist (HAZMat, Hospital Staff) & Unmanned Vehicle

INPUTS:

- (0027) Hazard Type
- (0109) & (0112) Contaminated Victim

RESULTS:

- (0115) Decontaminated Responder

77) T: +06:15 C: +00:15 3:15 pm

Events: The ECC's Field Incident Response Situation Team (FIRST) deploys with the mobile command post and takes over all tasks normally handled within the center including notifications and requests for additional resources.

User Levels / Information Flow:

- Incident Commander (EOC), Division Chief (various), & Team Leader (various)

INPUTS:

- (0128) National Incident Command System
- (0125) Victim Awareness
- (0145) Incident Report
- (0051) Life Safety Assessment
- (0044) Epidemiological Assessment Report
- (0089) Hazard Control Assessment
- (0127) Conditions at variance with plans and procedures
- (0126) Availability of time

RESULTS:

- (0130) Response requirements

- Operations Chief (EOC)

INPUTS:

- (0130) Response requirements
- (0134) Decision to active the FIRST
- (0135) Current facility operating status
- (0136) Time availably
- (0137) Staff availability
- (0138) Conations at variance with plans and procedures
- (0139) Plans and procedures appropriate for type of incident

RESULTS:

- (0133) EOC status

78) T: +06:16 C: +00:16 3:16 pm

Events: A First responder notices that 8 of the derailed and several damaged tanker cars are marked as carrying Vinyl Chloride. One of these 8 chemical tank cars has a slow release of chemical that is assumed to be Vinyl Chloride. Two more cars marked as carrying Organophosphates are badly damaged and appear to be the source of spilled product surrounding the site in solid form.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: early detection and observation of tankers, assisting in identifying agent dispersion patterns and levels

Events with UVs: The UV-D and UV-ST notice that 8 of the derailed and several damaged tanker cars are marked as carrying

Vinyl Chloride. One of these 8 chemical tank cars has a slow release of chemical that is identified to be Vinyl Chloride by the UV-I. Two more cars marked as carrying Organophosphates are badly damaged and appear to be the source of spilled product surrounding the site in solid form.

User Levels / Information Flow:

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0001) Chemical detection readings

RESULTS:

- (0022) Incident Information
- (0027) Hazard report
- (0034) Structural reports

79) T: +06:17 C: +00:17 3:17 pm

Events: Incident Command requests HAZMAT assistance and issues evacuation and shelter-in-place orders for the surrounding businesses and residences.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns.

Events: Incident Command requests HAZMAT assistance and issues evacuation and shelter-in-place orders for the surrounding businesses and residences. The UV-D, UV-I, and UV-ST assets in establishing the locations for evacuation and shelter-in-place based on agent dispersion models.

User Levels / Information Flow:

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information

o (0016) Pre-assessment report

RESULTS:

o (0049) Downwind hazard analysis

o (0043) Scene Report

80) T: +06:18 C: +00:18 3:18 pm

Events: Local media arrive and begin interviewing victims

81) T: +06:20 C: +00:20 3:20 pm

Events: Incident Command requests police assistance in establishing a perimeter.

User Levels / Information Flow:

- Incident Commander (IC Staff)

INPUTS:

o (0051) Life Safety Assessment

RESULTS:

o (0130) Response Requirements

82) T: +06:20 E: +02:20 3:20 pm

Events: The Secretary of the U.S. Department of Homeland Security issues a statement that the government has activated the National Response Plan

User Levels / Information Flow:

- Incident Commander (EOC)

INPUTS:

o (0156) Information Status

RESULTS:

o

83) T: +06:21 C: +00:21 3:21 pm

Events: Liquid gas has spread along the ground and collected in low and confined areas.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns.

Events with UVs: The UV-D, UV-I, and UV-ST have discovered that the liquid gas has spread along the ground and collected in low and confined areas.

User Levels / Information Flow:

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:
- (0032) Maps
- (0009) Hazard description information
- (0016) Pre-assessment report
- (0001) Chemical detection readings

RESULTS:
- (0027) Hazard report

84) T: +06:24 C: +00:24 3:24 pm

Events: HAZMAT team arrives and begins establishing the response zone with police assistance. Decontamination teams are requested to decontaminate First responders, freight train workers, on-lookers who are in the immediate accident area and their exposed vehicles.

UV Tasks: decontamination

UV Types: UV-DC (Inmobot, #1-2)

Improvements: reliable decontamination with quality assurances

Events with UVs: HAZMAT team arrives and begins establishing the response zone with police assistance. Decontamination teams are requested to decontaminate First responders, freight train workers, on-lookers who are in the immediate accident area and their exposed vehicles. The teams use the UV-DC for human decontamination.

User Levels / Information Flow:

For Decontamination UV (UV-DC):

- UV Specialist (HAZMat) & Unmanned Vehicle

INPUTS:
- (0027) Hazard Type
- (0168) Contaminated Responder

RESULTS:
- (0115) Decontaminated Responder
- (0169) Decontaminated Responder

85) T: +06:27 C: +00:27 3:27 pm

Events: Traffic in and out of the area is being rerouted.

User Levels / Information Flow:

- Division Chief (Law Enforcement), Team Leader (Law Enforcement), & Human Teammates (Law Enforcement)

INPUTS:
- ?

RESULTS:

o (0047) Traffic impact prediction

86) T: +06:30 C: +00:30 3:30 pm

Events: CSX notified the NRC of the train derailment and chemical spill.

User Levels / Information Flow:

- Operations Chief (EOC), Division Chief (EOC)

INPUTS:

o (0027) Hazard report

RESULTS:

o (0051) Life Safety Assessment

87) T: +06:30 E: +02:30 3:30 pm

Events: All Davidson County hospitals provide patient stabilization and transfer to outlying counties.

User Levels / Information Flow:

- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:

o (0124) Victim Tracking Information

RESULTS:

o (0125) Victim Awareness

88) T: +06:30 B: +06:30 3:30 pm

Events: TN Public Health releases a public announcement on the situation and provides information on dispensing station locations and distribution of antibiotics.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

o (0157) Disease control plans

RESULTS:

o (0156) Information Status

- Team Leader (Public Health) & Human Teammate (Public Health)

INPUTS:

o ?

RESULTS:

o (0157) Disease control plans

89) T: +06:49 C: +00:49 3:49 pm

Events: Large crowds of onlookers have formed around the area.

User Levels / Information Flow:

- Team Leader (Law Enforcement) & Human Teammate (Law Enforcement)

INPUTS:

- (0030) Emergency Management Information System

RESULTS:

- (0043) Scene Report

- Victims/ Civilians

90) T: +06:53 C: +00:53 3:53 pm

Events: HAZMAT teams begin trying to determine the condition of the cars containing the vinyl chloride and how much of the chemicals have spilled.

UV Tasks: detection, identification, scene tracking, and Hazard Removal

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns, early detect of tanker conditions

Events with UVs: HAZMAT teams with the use of UV-D, UV-I, and UV-ST begin trying to determine the condition of the cars containing the vinyl chloride and how much of the chemicals have spilled.

User Levels / Information Flow:

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0016) Pre-assessment report
- (0001) Chemical detection readings
- (0026) Classification mechanisms

RESULTS:

- (0027) Hazard report
- (0034) Structural reports
- (0043) Scene report

91) T: +07:00 C: +01:00 4:00 pm

Events: Unified Command for the train derailment is established.

92) T: +07:00 C: +01:00 4:00 pm

Events: Local volunteer services/agencies begin providing sheltering services.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- (0155) Local Government Status

RESULTS:

- (0156) Information Status

- Team Leader & Human Teammates (EOC)

INPUTS:

- (0130) Response Requirements
- (0154) Availability of time
- (0153) Memorandum of Agreements
- (0152) Knowledge of plans, procedures, laws, and regulations

RESULTS:

- (0155) Local Government Status

93) T: +07:05 C: +01:05 4:05 pm

Events: Civil Air Patrol does fly over to provide live feedback to EOC.

UV Tasks: scene tracking

UV Types: UV-ST (Blimp, #1+)

Improvements: deployment speed, scene stability, close (zoom-in'ed) imagery

Events with UVs: The UV-ST provides live feed for the EOC of the scene and provides angles not attainable by the Civil Air Patrol fly over.

User Levels / Information Flow:

For Scene/Object Tracking (UV-ST)

- Team Leader (Law Enforcement), UV Specialist (Law Enforcement), UV Teammates (Law Enforcement), & Unmanned Vehicle

INPUTS:

- (0030) Emergency Management Information System

RESULTS:

- (0031) Imagery
- (0034) Structural Reports
- (0035) Augmented Maps
- (0043) Scene Report

94) T: +07: 09 C: +01:09 4:09 pm

Events: A spokesperson from Unified Command begins fielding media inquiries.

User Levels / Information Flow:

- Operations Chief (EOC) & Division Chief (EOC)

INPUTS:

- (0155) Local Communication Status

RESULTS:

- (0156) Information Status

95) T: +07: 16 C: +01:16 4:16 pm

Events: The Williamson County Emergency Operations Center (EOC) is activated. Davidson County is monitoring the situation and providing support.

User Levels / Information Flow:

- Operations Chief (EOC)

INPUTS:

- (0133) EOC status

RESULTS:

96) T: +07:31 C: +01:31 4:31 pm

Events: The determination is made that the chemicals leaking from the damaged cars are Methyl Parathon (2 cars) and Vinyl Chloride (slow release from 1 car).

UV Tasks: identification

UV Types: UV-I (Quadrotor, Ground, or Blimp, #1+)

Improvements: Early identification, in-place identification, removal of risk from responders, reduction in contamination spread.

Events with UVs: The UV-I assisted in determining that the chemicals leaking from the damaged cars are Methyl Parathon (2 cars) and Vinyl Chloride (slow release from 1 car).

User Levels / Information Flow:

Identification UV (UV-I)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0026) Classification mechanisms
- (0001) chemical detection readings

RESULTS:

- (0027) Hazard report

97) T: +07:33 C: +01:33 4:33 pm

Events: Unified Command requests those within a 2-mile radius turn off air conditioners and remain inside.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns
Events with UVs: Unified Command requests those within a 2-mile radius turn off air conditioners and remain inside. This is based on information regarding the agents dispersion as gather by the UV-D, UV-I, and UV-ST.
User Levels / Information Flow:

- Team Leader (HAZMat), Human Teammates (HAZMat)

INPUTS:

- (0070) Types of contaminates
- (0069) Isolation methods
- (0061) Size of scene
- (0049) Downwind hazard analysis
- (0043) Scene Report

RESULTS:

- (0050) Protective actions recommended
- (0071) Isolation method

For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (HAZMat), UV Specialist (HAZMat), UV Teammates (Law Enforcement, HAZMat), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0016) Pre-assessment report

RESULTS:

- (0049) Downwind hazard analysis
- (0043) Scene Report

98) T: +07:58 C: +01:58 4:58 pm

Events: Hospitals are overwhelmed with people requesting information.
User Levels / Information Flow:

- Human Teammates
- Victims/ Civilians

99) T: +08:00 E: +04:00 5:00 pm

Events: All hospitals report patients overflowing the waiting areas. Public Health requests activation of the Medical Reserve Corps.
User Levels / Information Flow:

- Division Chief
- Human Teammates
- Victims/ Civilians

100) T: +08:30 C: +02:30 5:30 pm

Events: The Williamson County Mayor makes a press announcement regarding the train derailment.

User Levels / Information Flow:

- Incident Commander
- Human Teammates

101) T: +08:31 C: +02:32 5:31 pm

Events: The First EPA OSC arrives on-scene. Two more are en route from Atlanta, GA. The OSC initiates air monitoring in support of the response effort for protection of response workers, as well as of the general public.

UV Tasks: detection, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)

Improvements: assist in identifying agent dispersion patterns, early detect of tanker conditions

Events with UVs: EPA OSC teams with the use of UV-D, and UV-ST initiates air monitoring in support of the response effort for protection of response workers, as well as of the general public

User Levels / Information Flow:

For Detection UV (UV-D), Scene/Object Tracking (UV-ST)

- Team Leader (EPA OSC), UV Specialist (EPA OSC), UV Teammates (EPA OSC), & Unmanned Vehicle

INPUTS:

- (0032) Maps
- (0009) Hazard description information
- (0016) Pre-assessment report
- (0006) Air monitoring devices

RESULTS:

- (0025) Hazardous readings
- (0027) Hazard report
- (0043) Scene report

102) T: +09:00 E: +05:00 6:00 pm

Events: State OSHA arrives.

User Levels / Information Flow:

- Operations Chief (EOC)

INPUTS:

- (0151) Responder Status

RESULTS:

- (0144) Logistics Status

- Operations Chief (EOC) & Staging Area Manager (EOC)

INPUTS:
- (0147) Responders capabilities
- (0146) Responders locations
- (0150) Affected areas
- (0149) Availability of responders & Augmentees
- (0148) Memorandums of Agreement
- (0130) Response Requirements

RESULTS:
- (0151) Responder Status

103) T: +09:30 C: +03:30 6:30 pm

Events: Preparations are initiated to patch the leaking cars with the goal of eventually moving them to a more stable location. Preparations are also made to initiate the transfer of product from the 7 full Vinyl Chloride cars.

UV Tasks: Hazard working

UV Types: UV-HD (ground)

Improvements: assist in patching the leaking cars thereby moving the HAZMat team farther from harm.

Events with UVs: Preparations are initiated to patch the leaking cars with the goal of eventually moving them to a more stable location. Preparations are also made to initiate the transfer of product from the 7 full Vinyl Chloride cars. The use of the UV-HD reduces the risk posed to the responders.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:
- (0085) Decontamination status
- (0087) General Isolation Status

RESULTS:
- (0086) General mitigate status
- (0089) Hazard Control Assessment

- UV Specialist (HAZMAT), Team Leader (HAZMAT), Human Teammates (HAZMAT), & Unmanned Vehicles.

For Hazard working (UV-HD)

INPUTS:

o

RESULTS:

o (0085) Decontamination status

104) T: +10:00 E: +06:00 7:00 pm

Events: At this time 193 victims have been recovered and transported to hospitals and 80 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:

o (0124) Victim Tracking Information

RESULTS:

o (0125) Victim Awareness

105) T: +10:00 C: +04:00 7:00 pm

Events: News outlets report 29 incident-related injuries and 79 victims with illnesses due to chemical spill.

106) T: +11:45 C: +05:45 8:45 pm

Events: The HAZMAT team seals the leak of the Vinyl Chloride tank car.

UV Tasks: Hazard working

UV Types: UV-HD (ground)

Improvements: assist in sealing the leak.

Events with UVs: The HAZMAT team uses the UV-HD to seal the leak of the Vinyl Chloride tank car.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

o (0085) Decontamination status

RESULTS:

o (0086) General mitigate status

- UV Specialist (HAZMAT), Team Leader (HAZMAT), Human Teammates (HAZMAT), & Unmanned Vehicles.

For Hazard working (UV-HD)

- Team Leader (HAZMAT)

INPUTS:

o

RESULTS:

o (0085) Decontamination status

107) T: +12:00 C: +06:00 9:00 pm

Events: The EPA OSC makes a request for the USCG Gulf Strike Team

User Levels / Information Flow:

- Division Chief (EPA OSC)

INPUTS:

- ?

RESULTS:

- (0130) Response requirements

108) T: +12:30 C: +06:30 9:30 pm

The search of residential properties for victims begins.

User Levels / Information Flow:

- Team Leader (Law Enforcement) & Human Teammate (Law Enforcement)

INPUTS:

- (0018) Victim data
- (0035) Augmented maps

RESULTS:

- (0043) Scene Report

109) T: +13:00 C: +07:00 10:00 pm **Events:** USCG Gulf Strike Team (GST) Level A Team personnel are being dispatched to the incident.

User Levels / Information Flow:

- Operations Chief (EOC)

INPUTS:

- (0151) Responder Status
- (0143) Supplies Status

RESULTS:

- (0144) Logistics Status

- Operations Chief (EOC) & Staging Area Manager (EOC)

INPUTS:

- (0147) Responders capabilities
- (0146) Responders locations

RESULTS:

- (0151) Responder Status

110) T: +14:00 C: +08:00 11:00 pm **Events:** The two additional EPA OSCs arrive from Atlanta and help the other OSC continue conducting air monitoring in affected areas prior to a door-to-door assessment of area residents by police and local officials. OSCs are also setting up an around-the-clock air monitoring program along a 200 yard perimeter around the derailment site for protections of response workers, as well as of the general public.

UV Tasks: detection, identification, and scene tracking

UV Types: UV-D (Quadrotor, #1+), UV-I (Quadrotor, Ground, or Blimp, #1+), UV-ST (Blimp, #1+)
Improvements: assist in identifying agent dispersion patterns
Events with UVs: The two additional EPA OSCs arrive from Atlanta and help the other OSC continue conducting air monitoring in affected areas prior to a door-to-door assessment of area residents by police and local officials. OSCs are also setting up an around-the-clock air monitoring program assisted by the use of the UV-D, UV-I, and UV-ST along a 200 yard perimeter around the derailment site for protections of response workers, as well as of the general public.
User Levels / Information Flow:
For Detection UV (UV-D), Identification UV (UV-I), Scene/Object Tracking (UV-ST)

- Team Leader (OSCs), UV Specialist (OSCs), UV Teammates (OSCs), & Unmanned Vehicle

INPUTS:
- o (0032) Maps
- o (0009) Hazard description information
- o (0016) Pre-assessment report

RESULTS:
- o (0049) Downwind hazard analysis
- o (0043) Scene Report
- o (0025) Hazardous reading
- o (0015) Hazard dispersion patterns

111) T: +16:00 E: +12:00 1:00 am

Events: At this time 201 victims have been recovered and transported to hospitals and 85 bodies or body parts have been recovered.
User Levels / Information Flow:

- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:
- o (0124) Victim Tracking Information

RESULTS:
- o (0125) Victim Awareness

112) T: +17:00 C: +11:00 2:00 am

Events: The decontamination of undamaged railcars begins.
User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

- (0085) Decontamination status

RESULTS:

- (0086) General mitigate status

113) T: +20:00 B: +20:00 5:00 am

Events: The SNS arrives in Homeland Security District -5 and begins breakdown and distribution of prophylaxis.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

- (0157) Disease control plans

RESULTS:

- (0156) Information Status

114) T: +21:39 C: +15:39 6:39 am

Events: The decontamination of undamaged railcars is complete.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

- (0085) Decontamination status

RESULTS:

- (0086) General mitigate status

115) T: +22:00 C: +16:00 7:00 am

Events: Operations are initiated to remove undamaged railcars from the incident scene. This involves working in from both ends of the derailment towards the damaged cars containing the chemicals.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

- (0084) Hazard removal status

RESULTS:

- (0086) General mitigate status

- Team Leader (HazMAT) & Human Teammates (HazMAT)

INPUTS:

- (0081) Awareness of evidence preservation needs
- (0080) Identification appropriate remove methods

- (0079) Available resources for removal
- (0027) Types of hazards
- (0077) Equipment already contaminated
- (0076) Cars to be removed
- (0075) Order to remove cars

RESULTS:

- (0084) Hazard removal status

116) T: +22:00 E: +18:00 7:00 am

Events: At this time 209 victims have been recovered and transported to hospitals and 121 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:

- (0124) Victim Tracking Information

RESULTS:

- (0125) Victim Awareness

117) T: +22:47 C: +16:47 7:47 am

Events: The USCG GST Level A Team has arrived from Mobile, GA and begins providing oversight of the derailment wrecking operation.

User Levels / Information Flow:

- Operations Chief (EOC)

INPUTS:

- (0151) Responder Status

RESULTS:

- (0144) Logistics Status

- Operations Chief (EOC) & Staging Area Manager (EOC)

INPUTS:

- (0147) Responders capabilities
- (0146) Responders locations

RESULTS:

- (151) Responder Status

118) T: +23:00 B: +23:00 8:00 am

Events: There are news reports of large crowds forming at the designated dispensing stations well before opening.

119) T: +24:00 B: +24:00 9:00 am

Events: Designated dispensing stations open.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:

- (0157) Disease control plans

RESULTS:
- (0156) Information Status

120) T: +24:00 C: +18:00 9:00 am

Events: Operations to remove undamaged railcars are suspended at the request of the Williamson County Sheriff in order to allow local officials to continue search and recovery operations in the area surrounding the derailment. EPA and GST conduct several level B entries in order to monitor for chemical levels in areas where local officials are working.

User Levels / Information Flow:
- Team Leader (EPA, GST) & Human Teammates (EPA, GST)

INPUTS:
- ?

RESULTS:
- (0102) Trapped Victims
- (0084) Hazard removal status

121) T: +24:19 C: +18:19 9:19 am

Events: All federal, state, and local personnel are organized into shifts within an ICS structure.

User Levels / Information Flow:
- Operations Chief (EOC)

INPUTS:
- (0151) Responder Status

RESULTS:
- (0144) Logistics Status

122) T: +26:32 C: +20:32 11:32 am **Events:** Residences and businesses near the derailment site remain evacuated.

User Levels / Information Flow:
- Division Chief (EOC) & Operations Chief (EOC)

INPUTS:
- (0043) Scene Report

RESULTS:
- (0051) Life Safety Assessment

123) T: +28:00 E: +24:00 1:00 pm **Events:** At this time 270 victims have been recovered and transported to hospitals and 229 bodies or body parts have been recovered.

User Levels / Information Flow:
- Division Chief (EMS) & Operations Chief (EOC)

INPUTS:
- (0124) Victim Tracking Information

RESULTS:
- (0125) Victim Awareness

124) T: +30:30 B: +30:30 3:30 pm **Events:** The media reports large crowds still at all of the dispensing stations. They report at least 200 more than are actually remaining.

125) T: +31:00 B: +31:00 4:00 pm **Events:** Public Health holds a news conference to discuss the dispensing stations.

User Levels / Information Flow:

- Division Chief (EOC) & Operations Chief (EOC)
  INPUTS:
  - (0157) Disease control plans

  RESULTS:
  - (0156) Information Status
- Team Leader (Public Health) & Human Teammate (Public Health)
  INPUTS:
  - ?

  RESULTS:
  - (0157) Disease control plans

126) T: +36:00 E: +32:00 9:00 pm **Events:** At this time, 300 victims have been recovered and transported to hospitals and 301 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (Medical) & Operations Chief (EOC)
  INPUTS:
  - (0124) Victim Tracking Information

  RESULTS:
  - (0125) Victim Awareness

127) T: +44:00 E: +40:00 5:00 am At this time, 300 victims have been recovered and transported to hospitals and 337 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (Hospital Staff) & Operations Chief (EOC)
  INPUTS:
  - (0124) Victim Tracking Information

  RESULTS:
  - (0125) Victim Awareness

128) T: +52:00 E: +48:00 1:00 pm **Events:** At this time, 300 victims have been recovered and transported to hospitals and 373 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (Hospital Staff) & Operations Chief (EOC)
  INPUTS:
    - (0124) Victim Tracking Information
  RESULTS:
    - (0125) Victim Awareness

129) T: +64:00 E: +60:00 1:00 am

Events: At this time, 300 victims have been recovered and transported to hospitals and 546 bodies or body parts have been recovered.

User Levels / Information Flow:

- Division Chief (Hospital Staff) & Operations Chief (EOC)
  INPUTS:
    - (0124) Victim Tracking Information
  RESULTS:
    - (0125) Victim Awareness

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