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USING MODEL-BASED SIMULATION FOR AUGMENTING INCIDENT COMMAND SYSTEM FOR DISASTER RESPONSE

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ABSTRACT

The National Incident Management System has become the dominant organizational model for the management of emergency and disaster response and recovery operations. The Incident Command System (ICS) provides reporting and operational templates that structure activities and the management of resources and communications during an incident or event. In an emergency situation, information can be sometimes contradictory and may not be “clean”. In order for Command Officers to maintain good situation awareness of these dynamic situations, the system should be able to adapt by taking into account the type of information available, the specific task at hand, and knowledge derived from the information integration agent. This paper presents a design of ICS model and discusses the simulation architecture to support ICS commanders to potentially minimize cognitive load on decision makers, exploit semantic relationships in reports and sensor data to advice of invisible occurrences to better reflect ongoing developments during crisis management.

1 INTRODUCTION

The National Incident Management System (NIMS) and the Incident Command System (ICS) possess strengths in unified command, common terminology, modular organization, management by objective, and hard limits on span-of-control, defined as the number of resources managed by any one individual. In addition to other organizational benefits, its limiting span-of-control protects decision makers and responders from cognitive overload and associated mental fatigue. Overtaxed decision makers are poor decision makers. Therefore, protections from cognitive overload are important in preventing hazards from becoming disasters. As new information is gathered, emergency response responsibilities are pushed further up the command chain and more experts and specialists are brought in to assist. When considering the resources in an emergency, time and money are vitally important. ICS command structure aids in the execution of these responsibilities but fails to adequately supply a strong communication line between the structures. This can lead to inconsistencies and errors in an event. In that same event, lack of communication can cost time that the Incident Commander may not have. Given this information, we propose that the best way to aid in the process is by making information that generally would be invisible to the IC more visible through cognitive modeling, and in doing so reducing the cognitive workload while aiding in the decision processes that are being made at that moment.

2 BACKGROUND

2.1 Overview of ICS System

The ICS is currently the dominant system for on-scene incident management in the United States. ICS provides reporting and operational templates that structure activities and resources during an incident or event and has been applied to a wide variety of different hazard and disaster scenarios (Adams et. al 2008, Andrew and Kendra 2012, Arnold et al. 2001, Gyorfi et al.2008, Hansen 2007, Moynihan 2009, Wenger, Quarantelli and Dynes 1990). ICS is used to organize both near-term and long-term field-level operations for a broad spectrum of emergencies, from small to complex incidents.ICS is normally structured to facilitate activities in five major functional areas: command, operations, planning, logistics, and finance and administration (ICS). A conceptual disaster response is represented in Figure 1. Even within this simple conceptual organization, there could be inherent “unseen problems” of relevance. For example, a commander at any level of the ICS hierarchy will assuredly be inundated with information and reports. Cognitive overload, potentiated by fatigue, could render critical problems invisible to the decision makers. Mistakes require more effort to correct, creating more fatigue and a lower threshold for cognitive overload. Poor presentation of actionable facts that does not take into account the needs of the commander run the risk of creating local-to-the- person feedback loop of decreasing efficacy.

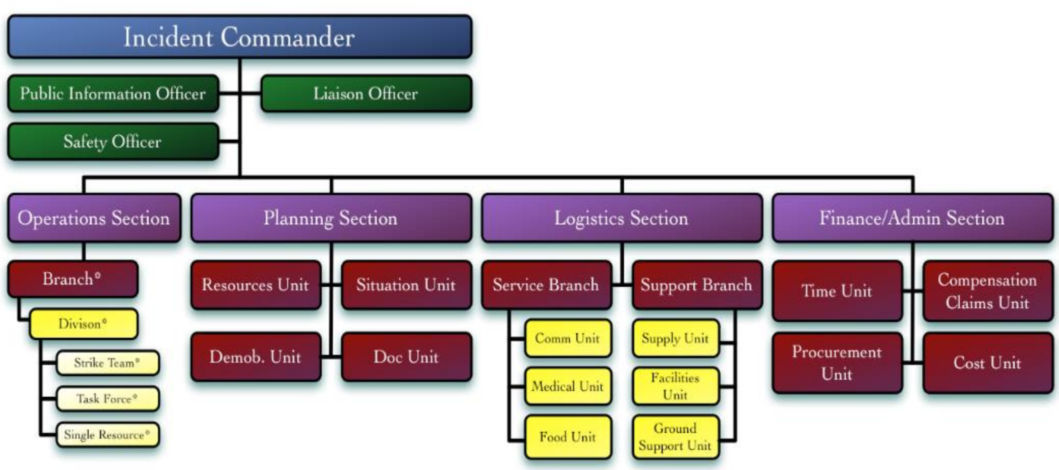

Figure 1: ICS Command Structure (Federal Emergency Management Agency (FEMA) 2008).

In large scale disasters, the incident command structure is well defined. At the top of the command is the Incident Commander (IC), a role that may be given initially to the responder who arrives first on the scene, but changes hands as higher ranking officials become involved in the incident. The IC is in charge of managing the response to the emergency. Working directly under the IC is Emergency Management Director.

Reporting directly to the IC are the Section Chiefs. The Planning Section Chief oversees the development of the Incident Action Plan (IAP) which identifies the strategies and tactics that will be utilized during the response phase to save lives, limit human suffering, and protect property. The knowledge of the various ICS forms is a very important part of the Planning Section Chief's role and is usually filled by a person who deals with these forms on a regular basis. The Operations Section Chief executes the incident action plan as devised by the Planning Section. The Logistics Section Chief is responsible for acquiring all the resources requested by any of the other sections or the IC. The Planning/ Finance Section Chief is responsible for tracking all expenses related to the response and recovery efforts. Financial data is critical for federal reimbursement as well as or insurance property coverage and replacement.

The Situation Unit Leader reports to the Planning Section Chief and collects and manages the data for the incident. This data includes weather forecasts, chemical plume data, buoy data, and more. This person must also monitor progress in the field and predict, based on current progress, what will need to be done in the next couple days.

The next roles are the directors of the First Responder branches. This includes the Hazmat, Fire, and EMS Branch directors. Each director oversees and manages their respective teams. They also collect data and submit reports to the Situation Unit Leader.

While not part of the ICS at the community level, the Emergency Management Director is responsible for mitigating the impacts of disasters on the community, planning and preparing for disasters before they occur, overseeing the operation of the Emergency Operations Center (EOC) to coordinate and support the resource and informational needs of the Incident Commander, and coordinating the recovery operations necessary to return the community to its normal state.

2.2 Agent-Based Simulation Model

An agent-based model is often used to simulate the events within and the interaction among elements of an autonomous system. Agent-based systems are made up of several components such as the agents themselves within the model, decision making rules, processes that adapt to dynamic events, a topology of interaction and finally the environment around the agents and every non agent component. It seeks to look at entities and their resources and how they impact the system as a whole. An agent-based model helps to understand how ICS works, how each of the components interacts with each other, and how they operate as a whole. Ultimately agent-based models help explore the behavior and interactions of individuals within a system, in order to solve or improve that system.

Agent-based modeling is a simulation technique that is used to model complex systems with multiple interacting, autonomous agents (Macal and North 2010). In this project, an emergency event is simulated with the help of agent model with an aim to reduce the cognitive workload of decision makers and first responders. An agent could be any computer system that senses the changes in the environment and executes actions accordingly in order to meet its design objectives (Jennings 2000). Agent-based modeling which was initially used in the field of artificial intelligence, was later extended to the field of software engineering, industrial process control etc. for its ability to make rational decisions depending upon the current state of the system (Wooldridge 1997). One of the major benefits of agent-based modeling is it can address emergent phenomena. The system whose individual behavior is difficult to formalize with the help of differential equations or the system whose behavior deviates from the predicted one due to some unusual interactions between the individuals gives rise to emergent phenomena. To deal with such situations, an agent-based model is the best choice of model (Bonabeau 2002).

Research in disaster management has used agent-based simulation (ABS). In a research study conducted by Hsu and Liu (2010), an agent-based model for natural disasters was built with the help of Agent-Based Disaster Simulation Environment framework along with a simulation engine. It was mainly done to understand the cause and effect of natural disasters. With the help of this model, the process change over time during a disaster can be modeled. One of the limitations of this model is that it did not take into account the different people and their roles during disaster management. Later, an ABS system was constructed for crowd evacuation during an emergency situation by Wagner and Agarwal (2014). The system was constructed using NetLogo and Java programming language. The model was created with an aim to assist the emergency responders in the planning and preparation during an emergency situation thereby acting as a decision support system for the emergency responders.

These studies focused on modeling of recovery during disasters. A few drawbacks were noticed from these studies include – a) not taking into account the actions associated with several actors in the event; b) lack of modeling of indicators designed by domain experts and c) lack of model validation.

3 MODEL FRAMEWORK

The following section describes the framework for the simulation model that is based on the cognitive model of the user for the specific system. Based on the model and environment inputs the simulation component provides feedback to the commander through an user interface. The user interface component is still in the development stage. The following section details the cognitive model used in the framework.

3.1 Operator Function Model as a tool

Operator Function Model (OFM) are established as a hierarchy of nodes of mental processes that take place in a single entity (Lee 2005). It is established to monitor the system and user in a complex system of events. A robust OFM model comprises of all possible operator control functions that are performed to achieve a goal. This model in conjunction with other models, can be used to assist decision making.

As shown in Figure 2, the top most node of an OFM is the primary task associated with all other tasks. All subsequent actions are done to fulfill the center node’s purpose. From there all nodes branching out are numbered and prioritized by an order with information leaving and entering the node (Lee 2005). In several cases, information must first be received before an action can be taken. This helps set the hierarchy of the nodes and establish a priority. In addition, several arrows may leave a node and go to a different node, but each arc must be numbered as a prioritized task. Information lower in number is always preferred to higher level information. At the same time, the primary objective cannot be completed until all tasks are completed. Every node has the potential to have subtasks that are necessary to be dealt with before moving on to the next node (Lee 2005). After creating an OFM for each entity that has some power in the ICS we hope to establish this primary task and identify redundancies.

3.2 OFM for the ICS

As shown in Figure 1, the ICS has several important individuals and each has a dynamic reaction to certain events in an emergency as well as specific skills that they can utilize. To give our model the most information, we map an OFM for each of the primary agents within the ICS. A robust model will aid in finding blind spots and may even help with interfacing with the agent when giving decision-making aids.

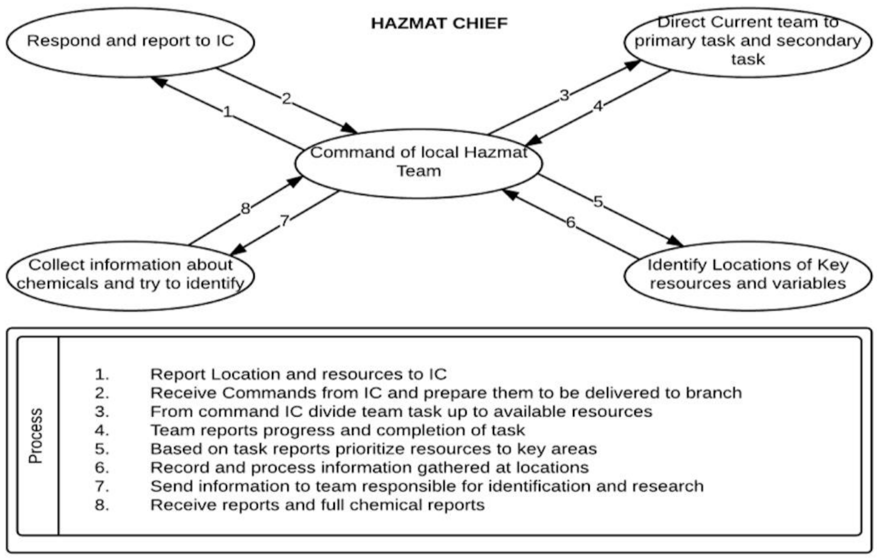

Figure 2: OFM Model.

For OFM, we use the model for the HAZMAT chief. The roles and priorities of the HAZMAT chief have been identified by using subject matter experts. The HAZMAT chief has to deal with all aspects of commanding the local HAZMAT team. As shown in Figure 3, there are four nodes representing Chief's activity. The first and foremost in the event of an emergency is to respond and report to the ICS. All higher level commands are sent from the ICS and the Chief lacks primary objectives without insight into the problem. Communication must come first within the ICS, so most OFM models would have this as a primary node. In addition to controlling the team, the chief must be aware of the availability of resources and factors that will be needed for responding to the IC. The IC may need several tasks done, and these need to be assigned appropriately based on available team members and resources. The team must know the appropriate objectives and have the resources to work with the unknowns of the emergencies. Thus the knowledge of objectives and the resources availability are the most crucial for ultimately identifying the chemical and releasing a response plan.

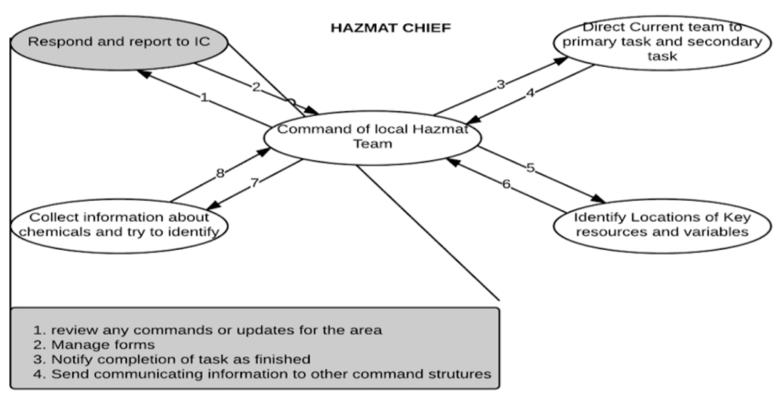

Figure 3: OFM Primary Node.

In Figure 4 below, we can see how each of these nodes have their own sub list that needs to be handled before information exchange can happen fluently.

Everything involving the IC is done based on the location and authority of the chief. Commands sent to the chief may require aid to other areas and many updates may come from other branch chiefs. This information is crucial for proper handling of the situation. The communication must be done at the very highest level. Once, the information is collected, it is documented in standard forms. Forms are necessary for communicating events to other teams in an objective way that can be recorded and monitored. Forms can be used for future and past events and may help aid in several different scenarios. Forms must be kept up to date with the IC as time develops and the situation changes. The IC needs to know in real time as each task is finished because that information may aid other operators in the scenario. For example, you would not want to destroy the wreckage before knowing that all samples and information have been collected from that wreckage. That could be a key to solving the overall problem and aiding in keeping the most people safe. Finally, the last step is responding to the IC is maintaining communication with all branch chiefs in order to know each other's whereabouts during the crisis at hand.

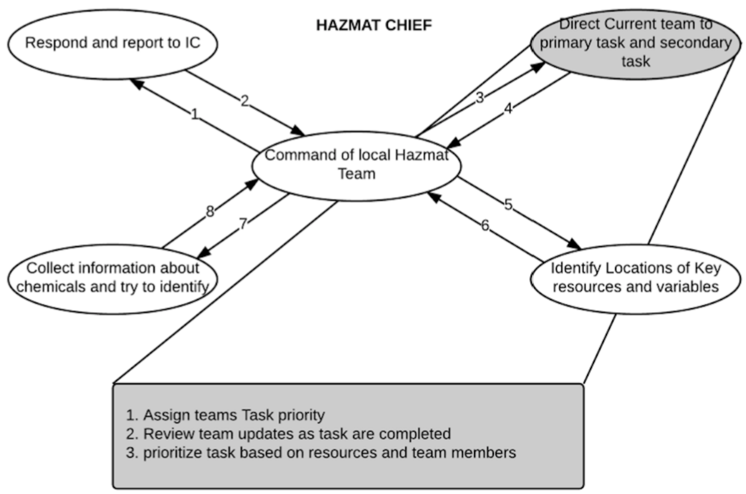

Figure 4: OFM Secondary Node.

The next part of the OFM examines team management and task assignment. Tasks need to be prioritized and assigned to the correct team with the correct resources. Then tasks need to be recorded as they are completed. Updates from one team may aid in the completion of other tasks with other teams. As resources are used and events are changed, tasks may need to be reassigned in order to complete them in the most effective and efficient manner. For example, if a single team doesn't have enough HAZMAT gear to tackle the chemical contamination you may have to reassign a secondary team to come and assist in completing that task.

Next as shown in Figure 5, it is important to account for, identify, monitor, and allocate resources. The HAZMAT Chief needs to know what type of chemicals we are dealing with and what resources he needs to mitigate their threat. That means he has to communicate with others and find out what they know. After that he needs to know what tests need to be performed to properly deal with the chemicals at hand, and how to properly treat the injured people in the area. As this information comes in, new tasks may be created that need to be prioritized where we again monitor resource consumption and try to maintain the correct amounts in order to deal with future problems.

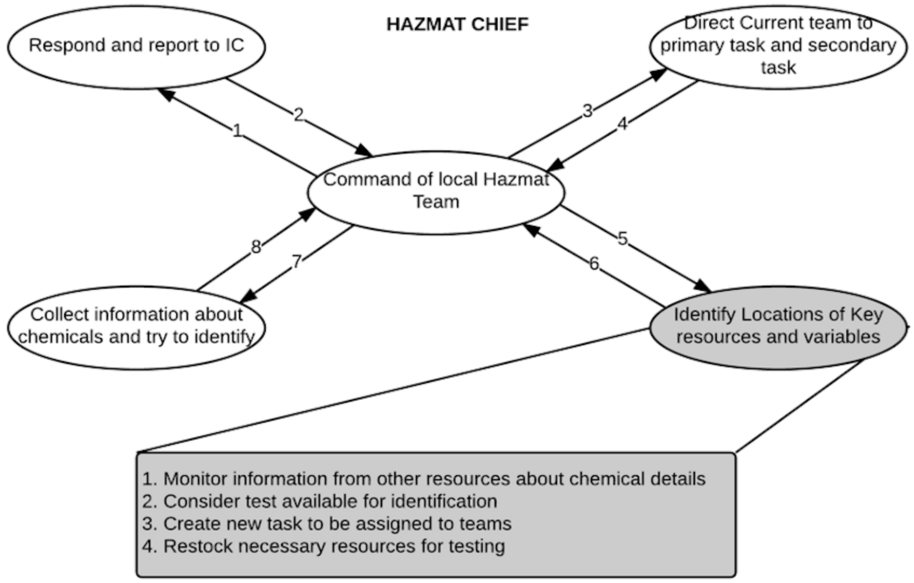

Figure 5: OFM Tertiary Node.

Finally, based on all the information collected, reports and surveys are created. This is represented in Figure 6. These can be reviewed, corrected and sent to labs as the event progresses. The information gathered will ultimately help in identifying chemical components and aiding the IC in properly handling the threat. Information may be gathered from media sources if it is affecting other individuals. The location of people giving out this information and potentially the context of how they came in contact with the chemical adds information that might not have previously been there. Until all the threats and chemicals are dealt with, all information is considered important and will ultimately help reach the final objectives. The complete model accounts for many interpersonal parts of the team as well as communication outside of what the HAZMAT chief controls. The process of going through all these prior activities gives us the best insight as to how the chief will perform in the event.

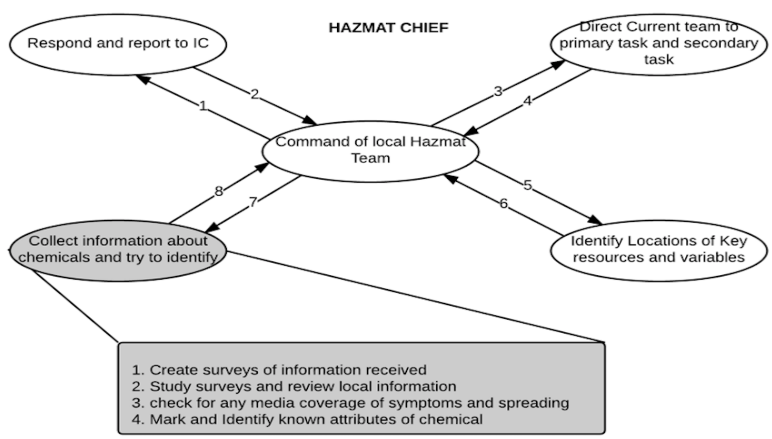

Figure 6: OFM Quaternary Node.

3.3 System Scenario Description

The simulation architecture was built on a disaster scenario designed by subject matter experts from National Center for Medical Readiness, Wright State University. The disaster scenario is based on a plane crash into a large chemical plant near a suburban city. The crash causes a large explosion as well as chemical leaks and exposure to the surrounding areas. The Local emergency stations immediately get reports from multiple 9-1-1 Calls, and social media reports several accounts of the event as well as providing photos and videos. Upon arrival, the first arriving fire truck reports a working industrial fire with numerous victims and a rapidly growing release of chemicals into the ground and air. The IC sets up command across the street from the plant and gives initial tactical direction to arriving units. Those directions are to establish a hot zone, remove viable victims out of the hot zone, and attempt to contain the fire. EMS units set up triage areas and begin to triage the first patients that are removed. Law enforcement is directed to evacuate the neighborhood immediately downwind of the toxic plume.

3.4 Simulation Architecture

All the modules are implemented in C#, and the database is connected using the MongoDB Bridge. The simulation architecture is based on an object-oriented discrete event architecture for interactive simulations. Interactive simulations allow a human-in-the-loop to act as a supervisory controller to monitor the information presented in the User-Interface (UI).

The architecture is based on Microsoft's model-view-view-model (MVVM) design paradigm. The MVVM pattern clearly defines responsibilities of each of the three layers. The model layer defines the business logic of the application including the business objects, data validation and data access rules. The view defines the user interface of the application and the user interacts with this layer. View-Model acts as a liaison between the model and the view and defines the presentation logic including the data to be displayed and methods to interact with both Model and View Layers. In the context of this study, the agent-based simulation logic and operational decisions are constantly updated to the Model component. The command officer views the complete process from the View component and takes decisions based on the current state of the system. Finally, ViewModel component acts as a bridge between model and view to listen for any changes and update the actions. Modularity and separation of concerns are emphasized by using this MVVM pattern.

As shown in Figure 7, in model-based design, often there are situations where the model dynamically changes the data and the agent has to be informed of the situation to expedite the decision making process. The simulation and operator functional model directly interact with the data viewed by the command officer. Therefore, we use MVVM design pattern to create a very strong dependency between incident commander and data binding logic, which is responsible for decision making.

In this architecture, the command officer, the human in-the-loop interacting with the simulation, uses a graphical user interface to monitor, plan and communicate with other actors to potentially reduce the cognitive workload of multiple agents present in the system. As multiple actors are involved in the process of decision making, there is always a possibility for unusual interactions. The View part of the architecture provides a snapshot of the entire system to the incident commander thereby ensuring all agents are informed about tasks to be performed. The Hazmat chief will be informed about the current state, information about chemicals and key resources available in order to perform the necessary task.

The View component is exclusively for the command officer. The simulation program written, has the Operator Functional Model logic which can bypass the human decisions on completely relevant situations. These decisions and actions are directly communicated with the backend MongoDB. The view part of the system is directly connected with the changes susceptible in the model components, updated by the OFM logic so that command officer is in unison with OFM. The user interface is designed in C#.

MongoDB is a document-oriented database, popular in production systems, which can handle huge amounts of data (Chodorow 2013). Critical data such as Person, Incidents, Hazmat, EMS and decisions taken are to be stored in a database. This model uses the information from the database and presents it in

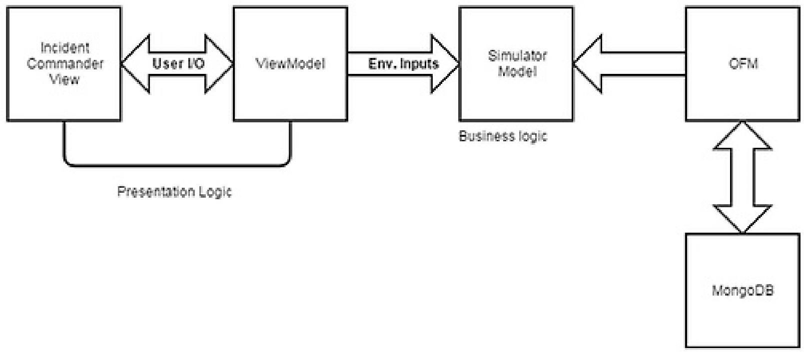

Figure 7: System Architecture.

the UI. OFM constantly monitors the ongoing process and updates the information with backend systems facilitating simulations to act as a bridge in planning and scheduling.

4 SUMMARY

Disaster management necessitates emergency operators and first responders to make critical decisions with extreme time constraints and includes multi-phase response operations and decisions made at one phase have a perceivable impact on all subsequent phases. These phases generate event data related to crisis response operations and software solutions that can be employed to analyze and glean critical insights from the generated event information. Hence it is important to design flexible systems that can help humans make informed decisions. Future work will focus on validating this study with the design of the test function exercise and the simulation model based on the Homeland Security Exercise and Evaluation Program (HSEEP).

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