Design and Development of a Virtual Emergency Operations Center for Disaster Management Research, Training, and Discovery

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Abstract

This paper describes the implementation plans and research activities of Project Ensayo, which is developing a virtual Emergency Operations Center (vEOC) based on one of the Nation's premier EOC's, that of Miami-Dade County. The goal of the EOC is to coordinate for 'community continuity', in other words help communities remain resilient in the face of disaster events. Organizations of this sort suffer from the lack of normal conditions that permit organizational learning in the traditional sense. The development of the Ensayo vEOC will support a portfolio of research projects including topics related to sensor data, knowledge and social networking modeling, decision-making, software approaches to commitment-based collaboration and coordination, time-critical negotiations under emergencies, and cyber-infrastructure resources.

1. Introduction

"Hurricane Katrina was an extraordinary act of nature that spawned a human tragedy. It was the most destructive natural disaster in American history, laying waste to 90,000 square miles of land, an area the size of the United Kingdom…claiming the lives of, more than 1500 people. The failure of the government at all levels to plan, prepare for and respond aggressively to the storm were due to four overarching factors: 1) long-term warning went unheeded and government officials neglected their duties to prepare for forewarned catastrophe; 2) government officials took insufficient actions or made poor decisions in the days immediately before and after landfall; 3) systems on which officials relied on to support their response efforts failed; and 4) government officials at all levels failed to provide effective leadership." [1].

An in-depth analysis of the response to Hurricane Katrina, one of the major natural disasters in the history of the United States, reveals widespread dissatisfaction with the results following the government's overwhelmed capabilities to respond [2]. In fact, the lessons learned from Katrina were very similar to those identified with Hurricane Andrew, which occurred ten years prior.

Problem solving in such disasters is difficult and dynamic, requiring rapid decisions before, during and after the event [2,3]. The number of organizations involved in emergency response ranges depending on the magnitude of the disaster. For example, it is estimated that around sixty organizations at the federal level alone, were involved in the recovery efforts following hurricane Katrina. Furthermore, voluntary organizations, such as the International Federation of Red Cross as well as local voluntary organizations, may follow a different set of protocols [3, 4]. Decision-making is often distributed, ad hoc, and made by individuals and institutions that do not normally interact, whose routines may not be sufficiently defined, relevant, or even known, and may lack substantial "institutional" memory as the institution itself is both emergent and ephemeral. However, there are many organizations and emergent groups that exceed at managing the complexities and uncertainties of disasters. Our ongoing research focuses on one of

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them—the Miami-Dade Emergency Operations Center [5-7]. Our overall research seeks to develop a simulation infrastructure that will enable the disaster management community to answer open research questions in the literature regarding effective recovery from disasters, including examining the properties of the particular organizational structure [8], explicating how learning occurs in rare-event and volatile environments [9], explaining how emergent groups are successfully integrated into the response [10], and how to dispel and respond to "myths" of disaster education [11]. Our primary approaches include in-depth analyses of this organization over time and incidents [12], and the development of a computational infra-structure—Ensayo—to generate simulated experiences in disaster scenarios based on the in-depth analyses. Our theoretical apparatus varies according to the level of focus; for example, it is firmly rooted in the underlying cognitive science of decision making at the individual level [13, 14], but broadens to include constructs at higher levels, such as team training theory [15] and virtual worlds learning [16], knowledge network analyses [17] and organizational learning [18].

2. Miami-Dade EOC

The state of Florida, with its long history of dealing with disasters particularly hurricanes, has designated the State Emergency Response Team (SERT) with the mission to "Ensure that Florida is prepared to respond to emergencies, recover from them, and mitigate against their impacts." The SERT has identified several hazards that pose an emergency threat to Florida, which include wildfires, thunderstorms, tornadoes, etc. A key entity of SERT is the Response Bureau which coordinates emergency response at the state level, and provides the necessary technical assistance to county governments. The Miami-Dade County Office of Emergency Management (OEM) is the lead agency in an emergency event and houses the Emergency Operations Center (EOC) where all emergency management operations take place. *It is important to understand that there is a well-defined structure for these groups and that is defined by the adoption of the national incident command system as the emergent organizational and communication structure of choice (HSPD-5, 2003). Specifically, this* system provides *"*a consistent nationwide approach for Federal, State, and local governments to work effectively and efficiently together to prepare for, respond to, and recover from domestic incidents, regardless of cause, size, or complexity*" (HSPD-5, 2003, p 1). Furthermore, this approach is expanding to critical non-governmental organizations, such as hospitals [19].*

Figure 1 depicts the organization for the operation of the EOC. Furthermore, Operations depends on a large array of organizations that are organized into three branches: the Public Safety Functional Group Branch, the Human Services Functional Group Branch, and the Infrastructure Functional Group Branch.

A number of additional organizations are represented in the periphery of the EOC: Florida Division of Emergency Management (DEM), neighboring county's emergency management liaisons, and the Divisional EOCs. In addition, representatives from Homestead Air Force Reserve Base and FEMA are also included.

During such events, critical decisions must be made that involve cross-organizational and cross-agency coordination, and sharing of data, information and knowledge. As these events and their contexts are infrequent and varied, the nature of the decisions, where they are made, who makes them, the data and information resources required to make and monitor them, and the location of available knowledge to drive them may sometimes be unknown, unavailable, or both. At the Miami-Dade EOC decisions are thoroughly documented via after action reports that cover a period of twelve hours before, during, and after the hurricane. But even though the Miami-Dade EOC is disciplined about recording the necessary documentation to prevent loosing their corporate memory, these after action reports may not cover every issue that needs to be dealt with during an emergency, as frequently unique and unanticipated events arise during each emergency situation. Furthermore, people may leave the organization, due to attrition or retirement, and some of the informal rules that serve as the "glue" that affords the very ability to function may be lost.

Coupled with these events are also the doubtful, but not negligible, coincidental disasters, which in general have not been explored. For example, there are substantial risks associated with coincidental events of terrorist opportunity. If airborne bio-terrorism agents were released during a hurricane, the resulting data would be available, but essentially masked within the structure and dynamics of unfolding events. Few, if any, decisions would be made regarding the masked attack. One mechanism to explicate, educate, and replicate these rules, both formal and informal, is through a computational discovery infrastructure for disaster management. That environment is called Ensayo.

3. Project Ensayo

Project Ensayo (Spanish for 'rehearsal') is a large, multidisciplinary effort that is focused on building a

computational discovery infrastructure to examine the decision-making and organizational complexities that arise from unique, complex, and significant events associated with the management of disasters, such as recovering from a hurricane in South Florida. Project Ensayo will support a community of researchers and thus enable multiple research projects investigating processes, functions and structures present at EOCs, including situational awareness, knowledge management, inferences from dynamic data, and mechanisms of command, control, communication, and coordination. The project team includes researchers from multiple institutions: Florida International University, Notre Dame, Emory, University of Puerto Rico Mayaguez, and MIT; a breadth of academic departments such as computer science, management information systems, electrical engineering; diverse research disciplines such as knowledge management, sensor networks, software development, cognitive science, computational discovery, human and social dynamics; and key external partners (Miami-Dade EOC, City of Miami, IBM, Florida Power & Light, and Public Health). The proposed Virtual EOC (vEOC) will support and enable multiple current and future research projects that would not be possible without the Ensayo vEOC.

The researchers are designing and developing, and will deploy and operate a virtual EOC. This environment will enable and support research on dynamic decision-making, decision support and knowledge management in the context of predefined organizational structures to coordinate cross-institutional management of disasters. The research infrastructure that will be designed and implemented in Project Ensayo will model the infrastructure of the Miami-Dade EOC. The project goal is to connect Ensayo to every key decision-making office in the Miami area that is responsible for decisions under the scenarios addressed, within the EOC context.

3.1. Research Objectives

Project Ensayo, the vEOC, will serve the following research objectives [6]:

i. A research-enabling environment and infrastructure to enable the research of knowledge management and collaboration issues in complex environments, such as those arising when managing disasters. Given that emergency management tasks are becoming increasingly complex and inter-organizational, effectively managing the various knowledge areas and organizations involved has become a critical emergency management success factor. However, there is a lack of theory and tools that organizations can use to assess and improve emergency management success through effectively managing task complexity and knowledge integration. The purpose of this research study, which is underway, is to attempt to address that gap by examining how the integration of specific knowledge can improve the inter-organizational task performance in emergency operations.

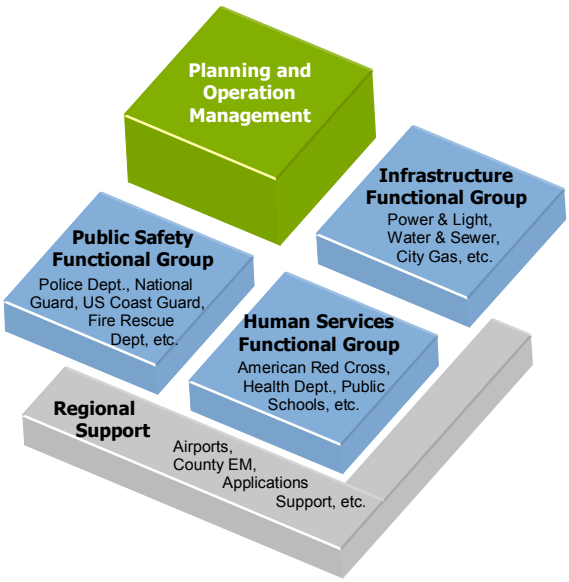

Figure 1: Emergency Operations Center Activation Floor Plan and Functional Organization

ii. A test-bed for policies, processes, best practices and disaster management technologies - aimed at improving both the effectiveness and efficiency in the management of disasters.

iii. An education and training facility for students, managers, and EOC staff across the world - by providing a pedagogical infrastructure for students on-site (same place) or off-site (different place), collaborating with other physical entities (real actors) or artificial agents (virtual actors).

The development of the vEOC is in itself an innovative research project, which requires the development of a collaboration platform to support Same-place or Different-place collaboration of EOC participants. At the same time the vEOC requires the development of Virtual actors (artificial agents) capable of collaborating with Real actors (physical agents) in a variety of scenarios. This project will enable the research team to set up and test the infrastructure for inter-university and inter-organizational collaboration, including both private

and public organizations, and to enable the research and training that will support degree programs from which the faculty and graduate students, many of them representing minority groups, will benefit.

3.2. Research Areas

A review of the literature in emergency response systems reveals that the disciplines of operations research and management science had a significant impact during the 1970s, which led to the implementation of substantially new policies and practices in policing and firefighting [20, 21]. On the other hand, recent disaster events, both in the US and around the World, have attracted our interest in this area as we witness that "some of these once-successful models have faded from use … while we observe the relative scarcity of papers on emergency services in recent years and ask whether the new attention on homeland security and emergency preparedness may presage renewed interest and activity in model development and application in these area" [22-24]. In addition, innovative computational techniques make possible new research approaches those were perhaps technologically or economically infeasible during the height of the emergency modeling of the 1970s [22, 25-29]. Finally, computational discovery techniques also enable the study of 9/11-type events, which are non-routine type emergencies that offer no practical ways to be validated.

Ensayo affords a remarkably broad arena for substantial research, in terms of underlying training and simulation technologies, integration with external technologies and data, human-computer interaction and visualization, data mining and knowledge mining methods, studies of individual and group decision-making, artificial intelligence/computational augmentation of disaster planning and execution components, and organizational communication and coordination investigations. For example, our team has developed a research portfolio that includes diverse areas of interest including:

1. sensor data: research aims at integrating simulated sensor data to wireless phone-based emergency response systems, seeking improvement in system performance. The research also deals with the concept of human sensors where individuals, communicating data through wireless devices such as cellular telephones, are modeled as information sources (see Figure 2). An approach to the research on human sensors addresses the entropic nature of coded files which combine data and metadata information;
2. knowledge and social networking modeling: concentrates on issues such as trust among EOC participants, organizational memory mechanisms to retain trust-based reputations, and trust placed in decision making;
3. decision-making: researches the adaptive nature of organizations and associated structures in the context of disaster management;
4. software approaches to commitment-based collaboration and coordination: studies with the objective of establishing the role of software in decision-making processes within and across the organizations;
5. time-critical negotiations under emergencies seeks to explain how negotiations and their commitments are conducted during disaster planning through recovery, leading to methods and mechanisms that can support this critical behavior in a more efficient and effective manner within the constraints of emergency operations; and
6. cyberinfrastructure resources: investigates, for example, the number of distinct agents and associated attributes needed to be developed in order to accurately represent decision-makers in the EOC.

The proposed research infrastructure will enable investigation into these research areas across multiple disciplines.

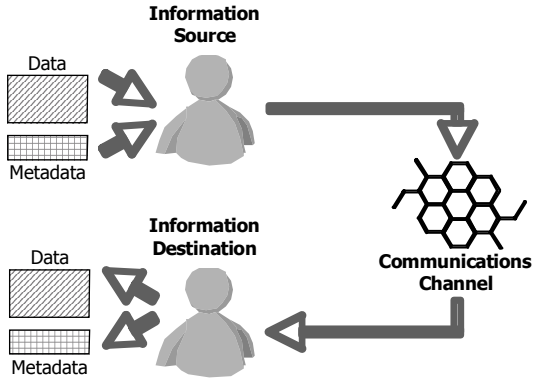

Figure 2: Humans as information sources: human sensors

3.3. System Engineering and Architecture

Ensayo's footprint is substantial, encompassing a shared, collaborative environment with both physical and artificial users. This environment is to operate as an EOC simulator and a trainer. In either mode it must be intuitive to use, easy to maintain, distributed (to enable the participation of geographically dispersed users and systems), and scalable. As project Ensayo is constructed, we can address these characteristics and ensure continuous progress by leveraging the spiral

development model. Given the magnitude of our vision for Ensayo, we seek to develop the vEOC functionality in an iterative manner, with each iteration providing increased refinement and additional capabilities.

Initially devised by Boehm [30, 31], the spiral model defines an iterative, prototyping method that leverages risk assessment throughout each cycle. For a project as substantial as Ensayo, it is imperative that, throughout development, communication with the end-users be ongoing and risks be uncovered and dealt with efficiently. As Guimarães and Vilela [32], Boehm et al. [31], and Pressman [33] indicate, the spiral model is well suited to this strategy for large-scale endeavors. Figure 3 offers a simplified depiction of the spiral model according to [33].

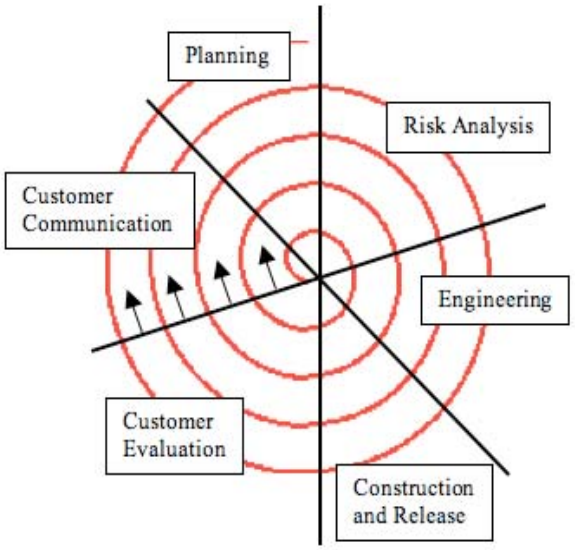

Figure 3: Simplified spiral model. From the spiral's center, the first iteration begins with customer communication and follows in the direction of the arrows. Each cycle around the model yields a more advanced prototype [33].

Three iterations of an Ensayo prototype will be derived over the course of the project. Each version of the prototype will represent one full iteration of the spiral model and offer increasing capabilities. The final prototype will be further refined into a production quality system.

The vEOC will ultimately be available as a resource to organizations around the world that lack such a disaster management tool. In addition, Ensayo can help serve the needs of the emerging disaster management research community. Specifically, this can include support for related work in the disciplines of computer and systems engineering, computer science, information systems, and management. Moreover, research on the vEOC platform can help reveal organizational issues that prevent efficient recovery from disasters. Also, Ensayo can support the development and testing of adequate information and communication technologies that enable the expeditious recovery of communities from disastrous events. In effect, these technologies help enable continuity of services during an emergency situation.

The first prototype will establish a basic distributed architecture within the open source Croquet environment. Built on Squeak (an open source implementation of the Smalltalk language), Croquet is designed for "creating and deploying deeply collaborative multi-user online applications on multiple operating systems and devices [34]." Croquet leverages its TeaTime architecture as the means for communication and synchronization of local and remote system objects [35]. Implemented as a peer-to-peer network, these objects share information and interact through simple message passing. By operating against a system of universal time coordinated among all peers, Croquet can enforce synchronicity and atomicity (through a two-phase commit process) in the objects and activities that peers host. This means that vEOC participants, regardless of their proximity to one another, will experience simulations and training in a coherent and simultaneous manner. The imperative goal of establishing the first Ensayo prototype within Croquet, then, is to derive fundamental EOC simulation and training capabilities (e.g., basic means of scripting and testing scenarios; support for local/remote, simultaneous users; support for a small number of simple, artificial users) that are collaborative and synchronous.

The components of the vEOC system as implemented in Croquet are depicted in Figure 4. Here, we see that all physical users connect to and replicate the original Croquet "island" (a collection of objects) containing the vEOC system; from then on, these users are synchronized peers of one another whose replicated islands communicate through message passing. In distinguishing between remote and local participants, a virtual private network (VPN) tunnel is used for secure, remote access to the vEOC's local area network (LAN).

Croquet's peer-to-peer network approach will also bring efficiency and resiliency to the vEOC deployment. Efficiency is gained as a result of replicating (at peer sites) not only the island containing vEOC components, but the computations as well. This may not seem intuitive at first, however, the implication is that by having "smart" copies of islands on all peers, instead of shuffling around large collections of data during a simulation/training session, minimal messages describing state and activities are transmitted. This also means that high-latency

participants will not necessarily slow down other peers. All peers operate against a coordinated time system, which maintains strict synchronicity. Slower peers will end up experiencing sluggish performance as they work to stay in synch, but all replicated islands will remain identical. Adding to this resiliency, Croquet objects track state information to enable recovery from system faults. This is a product of the two-phase commit protocol that Croquet uses to ensure atomicity of behaviors among peers.

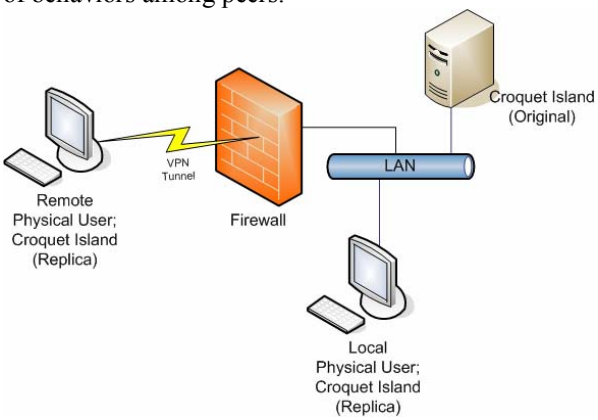

Figure 4: Ensayo architecture under Croquet

Also included in the first prototype will be a multi-user, desktop virtual reality (desktop-VR) interface to make interactions with some of Ensayo more intuitive and natural. The use of VR in this fashion can offer advantages in terms of user interfaces, training, and collaboration (e.g., see [36-39]). An early VR model based on the Miami-Dade EOC is shown in Figures 5a and 5b. Along with other Ensayo features, the desktop-VR interface will evolve from one prototype to the next, accommodating greater and greater functionality.

The second Ensayo prototype will build upon the first by introducing more dynamism into various vEOC mechanisms. Specifically, the artificial users and simulation/training processes will become less static (tied exclusively to a static script) and more dynamic: able to react in a realistic fashion to the actions and choices of physical users. The specification of an XML-based Ensayo dynamic scripting language will begin during this period.

The third Ensayo prototype will enable more realistic simulations and enhanced training. During a simulation, the collaborative, multi-user environment will better align with a real EOC in which people move about an emergency operations center, interacting directly with one and other during activation. Where training is concerned, powerful communication and workflow mechanisms will allow physical users to address each other (through text and voice chat) and propagate electronic files, maps, and other EOC-related documents from one avatar to another.

Figure 5a: Sample VR interface. View toward the strategy room in the virtual Miami-Dade EOC

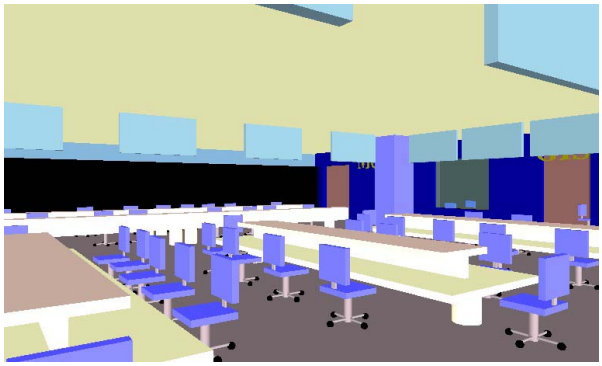

Figure 5b: Sample VR interface. View looking over the main operations room in the virtual Miami-Dade EOC

The central approach to desktop-VR will leverage the built-in VR abilities of Croquet along with the Virtual Reality Modeling Language '97 (VRML97) ISO/IEC standard. Maintained by the Web3D Consortium, VRML is a mature, open specification for 3D geometry and runtime behavior [40]. By using VRML97 the process of building and incorporating models such as that depicted in Figures 5a and 5b becomes straightforward. Different operations center layouts and simulations of outdoor environments (e.g., cities, ocean fronts) are possibilities afforded through the use of VRML97 and Croquet's VR mechanisms. This will be woven in to the XML-based Ensayo scripting language.

Though not specifically discussed alongside the prototypes, two threads that will run throughout the development effort are metrics and security. The former is essential to any simulation and training environment, since measurements that are accurate and meaningful will enable a pedagogical end-user

experience. Metrics will be realized in the form of logging (i.e., process and event tracing, error tracking), scoring, and qualitative feedback.

Security mechanisms are needed to manage physical users and ensure simulation/training privacy and integrity. Users will be required to identify themselves to the vEOC system with a valid account ID and password. Account roles (e.g., user, administrator, guest) will provide authorization. Strong encryption (e.g., VPN tunneling) will be used to ensure the privacy and integrity of all remote Ensayo communications and workflow.

4. Conclusions

The Ensayo virtual Emergency Operations Center is being developed in collaboration with the Miami-Dade EOC. The Miami-Dade EOC exists to facilitate the coordination of organizations that, other than during emergencies, don't collaborate with each other. Organizations of this sort suffer from the lack of normal conditions that permit organizational learning in the traditional sense The goal of the EOC is to coordinate for 'community continuity', in other words help communities remain resilient in the face of disaster events. We foresee that Ensayo provide the needed infrastructure to a community of researchers that will contribute to better understand and find solutions to the challenges faced by this type of organizations that continue to serve our communities in times of need.

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