Emergent Interoperability: Collaborative Adhocracies and Mix and Match Technologies in Emergency Management

David Mendonça, Theresa Jefferson, John Harrald

1 Planning and Improvisation in Response to Extreme Events

Large-scale emergencies—commonly called extreme events—create sudden and profound changes in human systems and the built environment, leading human to response activities that range from planned to improvised, as conducted both by established and ac hoc organizations. Indeed, despite improvements in information and communication technology (ICT), the role of improvisation, adhocracy and other emergent phenomena in emergency response has not diminished. As reported in many years of research on human response to extreme events, successful response is likely to require personnel to think in ways that differ—sometimes radically—from plan [1]. To meet response goals, personnel may take on new or expanded roles [2, 3], develop new organizational structures [4], and adapt existing technologies to unforeseen needs. These actions require improvisation: a combined cognitive and behavioral activity which is creative but purposeful, and which must be accomplished serially, with little or no chance of revision [1]. The environment required to provide ICT-based support for improvisation is one that facilitates emergent interoperability: that is, a structured approach to real-time mixing and matching of diverse ICTs to support individuals and organizations in undertaking response activities.

Even from the most recent past, it is possible to identify many ways in which incorrect models of post-extreme event environment may be seen as root causes of ICT failures during response [5, 6]:

- the fallacy of the hierarchical, military model managing complex response as an "incident." Responding to an extreme event requires collaboration, cooperation and transparency by numerous organizations with different cultures and structures. These values are not embedded in the hierarchical, military model.
- the fallacy of developing all-inclusive doctrines and procedures to guide complex response. Extreme events occur infrequently, and no two are exactly the same. A comprehensive set of procedures to cover the space of possible events may be impossible to achieve. Perhaps more to the point, tightly constraining response activities can limit opportunities for expanding the set of possible solutions to disaster problems.
- the fallacy of achieving common operating picture and situational awareness. The concept of shared situational awareness and common operating picture originates from the domains of aviation safety and military combat. In contrast, the emergency management environment, while also complex, is highly heterogeneous. When evaluating the role of shared situational awareness it must be recognized that not all actors involved in the response to an extreme event will require access to all relevant information. When

attempting to consolidate information to obtain a shared situational awareness there is a very real possibility that information that is relevant to one or more parties will be inadvertently left out.

This paper investigates how the process of ICT design may be undertaken in order to achieve emergent interoperability during emergency response. The question of ICT design is approached as a research problem whose solution is bound with the underlying cognitive, behavioral and communication phenomena that ICT is intended to support. The paper concludes with a description of current and recommended lines of research that, if pursued, may enable the design of ICT to support the types of organizations that actually conduct response. The result is denoted emergent interoperability, since it underscores the importance of a disciplined approach to achieving flexibility and improvisation.

2 Societal Response: Adhocracies and Emergent Processes

Extreme events may be regarded as events which are rare, uncertain and have potentially high and broad consequences [1]. Responding to them is likely to require multiple decision makers who must reason, communicate and make decisions about complex systems such as inter-related networks of personnel and material resources. This collaboration involves individuals, groups and organizations who have different backgrounds and levels of experience in working together. The characteristics of extreme event response, coupled with the diverse backgrounds of response personnel and their evolving scope of activities, contribute to the need for responding personnel to improvise or "make do" with those personnel and material resources which can be made available in time to meet goals of the response.

Improvisation in emergency response has long been viewed as a combined cognitive, behavioral and social activity in which creativity is exercised under time constraint in order to meet response objectives [3]. When unplanned-for contingencies arise during emergency response, personnel have a two-fold cognitive task [1]. First is to determine whether a procedure (such as a plan) can be matched with the contingency. Second, depending on the outcome of the first task, they will either execute the planned-for procedure or develop a new one. Given the high time constraint of emergencies, decisions are likely to be made incrementally, often with considerable importance placed on feedback from the field [4]. Future decisions are therefore constrained by and conditioned on past ones—as well as on expectations of future states. An understanding of the cognitive processes underlying response task provides the basis for developing ICT support for response activities.

Cognition is bound with role performance: that is, in the execution of a set of behaviors that an individual is expected to be able to perform. Role improvisation occurs when response personnel perform roles that differ from those for which they have been trained [2]. Role improvisation is an abiding feature of emergency response, manifested by both professionals and non-professionals [3].

Relationships within and among organizations directly impact the success of emergency response operations [4]. Pre-disaster organizational structures are planned-for, since they are created to meet anticipated contingencies. In contrast, post-disaster organizational structures are shaped by both anticipated and unanticipated contingencies. The result is a set of (possibly

overlapping) organizations that range from planned to *ad hoc* [7]. The scale of extreme event response may require communications amongst geographically and temporally dispersed personnel, heightening the need for timely and accurate feedback on conditions in the field [4]. For collaborative relationships to be effective it is necessary to recognize the values and goals of the individual members. The objectives of the collaborative partnership must incorporate these individual perspectives in order to ensure stakeholder buy in and a commitment to the collaborative effort. Without committed members, the collaborative relationship will not succeed. Collaboration—the process by which members of responding organizations think, work and communicate to achieve common objectives—therefore has a central role in determining the effectiveness of emergency response.

3 Designing for Emergence to Support Improvisation

Responding to emergencies requires a range of response tasks, varying in scope and complexity, as well as in their means of execution. When planned-for supporting technologies cannot be used or are inadequate, response personnel may require guidance on how to mix and match other technologies in order to develop tools that fit the tasks at hand. More broadly speaking, the space of possible contingencies for extreme events is so large as to preclude their exhaustive enumeration. As a result, pre-defining ICT for the set of possible conditions leads to a theoretical and practical cul-de-sac. As discussed in this and the following section, a more productive avenue of inquiry is in developing systems that suggest processes (rather than outcomes), as derived from an understanding of underlying cognitive, behavioral and communications phenomena. Developing a theoretical basis for this understanding would contribute directly to the broader question of how to design for fit between response tasks and the technologies to support personnel in meeting task requirements.

Theories of task-technology fit seek to provide prescriptive guidance about which computer technologies are best suited to supporting particular tasks [8]. According to Campbell [9], a task is defined as the behavior requirements for accomplishing stated goals, via some process, using given information. Zigurs and Buckland [8] propose five categories of tasks: *simple* tasks, which have a single outcome and decision scheme; *problem solving* tasks, which involve finding the best way to satisfy a single criterion; *decision* tasks, in which "choosing or discovering an outcome that optimally achieves multiple desired end states" is emphasized; *judgment* tasks, in which task-associated information is "conflicting and probabilistic in nature;" *problem* tasks, in which there is "a multiplicity of paths to a well-specified, desired outcome;" and *fuzzy* tasks, which include "both multiple desired end-states and multiple ways of attaining each of the desired outcomes." As is evident from the prior discussion and numerous prior studies, tasks across this entire range will be required during the response to extreme events.

An information and communication technology may be classified according to the combination of process structuring, communication and information processing support it best provides [8]. For example, judgment tasks are hypothesized to require support from communication and information processing technologies [8]. Yet while task-technology fit theory provides a starting point for guiding ICT design, two factors common to the extreme event situation have the potential to impact fit, but to a large extent are unexplored in the context of ICT use for emergency response.

The first factor is the degree of improvisation required or practiced by individuals and organizations. The individuals and organizations involved in the response may be professionals or non-professionals, who either follow their roles or improvise them [2, 3]. Role improvisation may require high degrees of judgment, often accompanied by input from others who are familiar with the performance of the improvised role. As a result, communication demands are expected to be high for all but the most simple tasks. At the organizational level, collaborative adhocracies will need to establish lines of communication (and, potentially, technological protocols for communication), also resulting in increased demands for communication support for all but simple tasks. Moreover, as suggested by the prior discussion, the quest to develop a common operating picture is based on an assumption that such a construct actually exists. A more reasonable assumption is that response operations are likely to include both centralized and distributed operations, undertaken by individuals as well as members of established and ad hoc organizations.

The second factor is the degree to which members of adhocracies and established organizations need to combine various types of ICT to meet response goals. The origins of this need are two-fold. First, planned-for technologies may simply be unavailable during response operations due to outages, so-called cannibalization or appropriation. Second, there may be situations of failing to "drop your tools" [10] (i.e., retaining technologies with poor fit to the task) or of failing to "know your tools" (i.e., not recognizing that a tool at hand is appropriate). Current instantiations of task-technology fit theory do not specify how prescribed technologies are to be combined. Moreover, technologies that provide only a single function (e.g., communication capability) are becoming more rare, not more common. For example, current cell phones provide not only communications support, but also information processing support since they are capable of integrating text and graphics. These technologies may be platform-dependent, limiting the extent to which they can be integrated with more advanced technologies, such as event models (e.g., those being developed for earthquakes) and sensor networks.

Taken together, the observations on these two factors suggest that the design of fit between task and technology in emergency response must be informed by understanding of adhocracies, the practice of improvisation and the implications of a functionality diverse and highly heterogeneous computing environment.

Some current research projects provide insights into how valid and reliable methods for achieving fit via emergent operability may be developed. Work flow models in software engineering specify a schedule of activities from design to implementation. Recent work is leading to work flow models that can accommodate and self-repair following disruption [11], thus supporting interoperability by enabling activities to be added, deleted or modified. A continuing problem in multi-organizational response is difficulty in resolving differences in how material and personnel resources are described. The resource mapping initiative by the US Federal Emergency Management Agency is intended to use ontologies to provide conceptual mappings among resources for the response. Possible extensions of this work are in linking resources to response activities. Interoperability requires reasoning about the functional capabilities of tools when intended to accomplish particular goals. Models that can undertake some phases of technological mixing and matching [1] may therefore be used to support response personnel in reasoning about ICT capabilities. Finally, research on emergent multi-

actor networks is being coupled with the development of sensor networks to provide information and make inferences about the evolution of communication networks during emergency response [7]. In the future, communication-based collaborative tools may help filter out duplicate and unessential information while placing emphasis on vital information.

4 Conclusions and Implications

Extreme events create large-scale and sudden changes in human systems and the built environment. The objective of emergency management is to make these systems more resistant to the impacts of extreme events, thus enhancing societal restoration and recovery. To contribute to the success of emergency response operations, ICT-based support must recognize three results from research on human response to emergencies: first, that a range of tasks, varying in their degree of improvisation, will be undertaken by response personnel; second, that the cognitive, behavioral and communication activities that underlie these tasks will be undertaken by personnel in established organizations and in adhocracies; and third that various ICTs will need to be mixed and matched to support personnel in accomplishing response tasks. Emergent interoperability is an approach to ICT design which recognizes the salience of unplanned-for contingencies during emergency response, and the concomitant need for real-time mixing and matching of these technologies.

Unfortunately, a focus on structure and doctrine obscures the need for technology that enhances improvisation and creativity. The specification and formalization of the planned-for structure has resulted in doctrine and technology to support it, ignoring the demonstrated, even inevitable, needs of the adhocracies which help manage the unanticipated contingencies presented by extreme events [12]. Shared situational awareness of a common operating picture is not a necessary precondition for enabling and supporting the distributed decisions and behaviors necessary for successful reaction to and management of the unexpected. The technological systems we design and build must enhance—not impede—organizational agility.

Improvisation and adhocracy have received considerable examination from social scientists, but have been far less frequently addressed by ICT designers. As a result, a systematic approach to ICT-based support for improvisation and adhocracy in emergency response has yet to be undertaken. It is time for the science and technology community to recognize that the threat of catastrophic events requires a better understanding of how decisions are made under complex, chaotic conditions and a recognition that information and communication technology can serve society, but only by supporting the adaptive, evolving processes and structures that will always occur during and after such events. Often the emergency management technology problem is viewed as a development issue, designing technology for known requirements and processes. We believe it is fundamentally a research issue, requiring that we integrate the best social science and technology research to understand and to solve the complex problems we face.

Acknowledgement: We thank the anonymous reviewers of this article for their many helpful comments.

5 References

[1] D. Mendonça and W. A. Wallace, "A Cognitive Model of Improvisation in Emergency Management," *IEEE Transactions on Systems, Man, and Cybernetics: Part A*, forthcoming.

[2] G. R. Webb, "Role Improvising during Crisis Situations," *International Journal of Emergency Management*, vol. 2, pp. 47-61, 2004.

[3] G. A. Kreps and S. L. Bosworth, "Disaster, Organizing and Role Enactment: A Structural Approach," *American Journal of Sociology*, vol. 99, pp. 428-463, 1993.

[4] T. E. Drabek and D. A. McEntire, "Emergent Phenomena and Multiorganizational Coordination in Disasters: Lessons from the Research Literature," *International Journal of Mass Emergencies and Disasters*, vol. 20, pp. 197-224, 2002.

[5] National Research Council, "Facing Hazards and Disasters: Understanding Human Dimensions," National Academies Press, Washington, DC 2006.

[6] T. Jefferson and J. R. Harrald, "Shared Situation Awareness in Emergency Management Mitigation and Response," presented at Hawaii International Conference on System Sciences, Big Island, forthcoming.

[7] C. T. Butts, M. Petrescu-Prahova, and B. R. Cross, "Responder Communication Networks in the World Trade Center Disaster: Implications for Modeling of Communication Within Emergency Settings.," *Journal of Mathematical Sociology*, forthcoming.

[8] I. Zigurs and B. K. Buckland, "A Theory of Task/Technology Fit and Group Support System Effectiveness," *MIS Quarterly*, vol. 22, pp. 313-334, 1998.

[9] D. J. Campbell, "Task Complexity: A Review and Analysis," *Academy of Management Review*, vol. 13, pp. 40-52, 1988.

[10] K. E. Weick, "Drop Your Tools: An Allegory for Organizational Studies," *Administrative Science Quarterly*, vol. 41, pp. 301-313, 1996.

[11] J. Wang, D. Rosca, W. Tepfenhart, A. Milewski, and M. Stoute, "An intuitive formal approach to dynamic workflow modeling and analysis," presented at Third International Conference on Business Process Management, Nancy, France, 2005.

[12] J. R. Harrald, "Agility and Discipline: Critical Success Factors for Disaster Response," *Annals of the American Academy of Political and Social Science*, vol. 604, pp. 256–272, 2006.

Authors' Biographies

David Mendonça is an Associate Professor in the Information Systems Department at New Jersey Institute of Technology. His current research is in modeling and supporting cognition in individual and group decision making during emergency response. He is a member of the Association for Computing Machinery, the Institute for Operations Research and Management Sciences and the IEEE.

Theresa Jefferson is an Assistant Professor of Engineering Management and Systems Engineering and research faculty for the Institute for Crisis, Disaster and Risk Management at The George Washington University. She is an Associate Editor for *VINE: The Journal of Information and Knowledge Management*.

John Harrald is the Director of the Institute of Crisis, Disaster, and Risk Management and Professor of Engineering Management and Systems Engineering at The George Washington University. He is on the Steering Committee of the National Research Council's Disaster Roundtable and is the Executive Editor of the *Journal of Homeland Security and Emergency Management*.