Towards Disaster e-Health Support Systems

José J. González
Centre for Integrated Emergency Management
University of Agder
josejg@uia.no

José H. Canós
ISSI - DSIC
Universitat Politécnica de Valéncia
jhcanos@dsic.upv.es

Tony Norris
School of Mathematics and Computer Science
Auckland University of Technology
tony.norris@aut.ac.nz

Reem Abbas
School of Mathematics and Computer Science
Auckland University of Technology
reem.abbas@aut.ac.nz

ABSTRACT

Disaster management and the health sector ought to be natural allies, but their different origins, culture, and priorities of the various agencies tasked with disaster response mean that communication and coordination between them is often lacking, leading to delayed, sub-standard, or inappropriate care for disaster victims. The potential of the new e-health technologies, such as the electronic health record, telehealth and mobile health, that are revolutionizing non-disaster healthcare, is also not being realised. These circumstances have led to an international project to develop a disaster e-health framework for the objectives of intelligent adaption to changing scenarios, presentation and management of information, and communication and collaboration. In this paper, we describe characteristics of disaster e-health support systems to achieve such set of objectives.

Keywords

Disaster e-health, disaster response, disaster e-health support system

MOTIVATION

In a major disaster[1], there are inevitably human casualties who need rapid treatment for trauma, and the specialised field of *disaster medicine* has evolved for this purpose (Hogan and Burstein, 2016). Essentially, disaster medicine applies public health and specialist tools to define clinical protocols in a disaster response. Other stages of the disaster management lifecycle are also in the scope of disaster medicine. On the one hand, within the preparedness stage, there is a need to teach the competencies required by clinical personnel to act under high pressure in an adverse work environment (Subbarao et al., 2008). On the other hand, disaster medicine is present also in the recovery stage since, as stated in (Galea, 2007), the health consequences of disasters, initially exhibited as fatalities and injuries, often appear years later as chronic and mental illnesses.

Modern medicine has changed dramatically with the advent of numerous information and communication technology (ICT) enabled tools, globally known as *e-health* applications or systems (Coiera, 2015). However, whilst disaster management has rapidly adopted and deployed ICTs to change for good the way the different stages of the disaster lifecycle are dealt with (Hristidis et al., 2010; Rao et al., 2007), there is little systematic use of modern e-health tools in disaster medicine (James and Walsh, 2011; Sakanushi et al., 2013). It is well known

[1] We use "disaster" as a generic term covering a range of disastrous events, from mild emergencies to catastrophes. We will use more specific terms when dealing with particular cases.

that e-health technologies like the electronic health record, tele-health systems, decision support systems, data analytics, RFID tagging, the Internet of things, cloud computing, social media, etc., are revolutionizing the planning and delivery of mainstream healthcare (Coiera, 2015). All of them can make health information and health-related services available anytime, anywhere, automate workflows, and provide seamless care for immediate intervention or longer-term treatment. They also *democratize* healthcare by encouraging the active participation of the citizen in the care process. Crucially, however, beyond the application of electronic triage and telemedicine, disaster medicine clinicians are seldom trained to be aware of these technologies, let alone to acquire competency in their use (Sakanushi, K et al. 2013; Doarn and Merrell, 2014).

The different origins, development, and priorities of disaster management and disaster medicine have led to a lack of communication and coordination across these disciplines during disasters, leading to delayed, sub-standard, inappropriate, or even unavailable care. This concern has prompted Bissell (2007) to write *"Emergency management and the health sector are natural allies that have, seemingly, only recently begun to recognize each other"*.

Since little progress had occurred in such respect, an international project was established to develop a new paradigm, called *Disaster e-health,* to fill the gap between disaster management and disaster medicine. Disaster e-health aims at promoting the application of e-health technologies to assist the prognosis and treatment of the sick and injured in a disaster, and to support appropriate care in the post-disaster situation. It can be thought of as a domain at the intersection of three constituent fields, namely disaster management, disaster medicine, and e-health.

The ISCRAM community and ISCRAM's annual international conferences created bonds between Auckland University of Technology, New Zealand, and the University of Agder, Norway. Both institutions conduct research on health, e-health and disaster management. The collaboration between research teams from both institutions to advance disaster e-health acted as a lever to improve disaster healthcare. The research group expanded quickly to incorporate expertise in information systems from the University of Nebraska, Omaha, USA, and has grown further to embrace researchers from universities in Canada, Bulgaria, Sweden, and France.

The DEH project has received grants that have led to the appointment of two PhD students at AUT. The research has succeeded in scoping the disaster e-health domain (Norris and Althwab, 2013; Norris et al., 2015) and developing key topics such as inter-agency communication, scenarios for disaster e-health applications, and education (Abbas et al., 2016). The grants have also served to run international workshops in Norway, the USA, and New Zealand as well as at the recent ISCRAM 2017 conference in France. The goal of these workshops has been to develop a roadmap for disaster e-health that accelerates its development and sets the domain on a path to becoming a vital and sustainable component of mainstream disaster healthcare.

Running in parallel with the DEH project, a European (EU) Horizon 2020 research project, with nine different countries involving cities and universities throughout Europe, has been looking at crisis and disaster resilience with a view to developing a holistic approach to resilience that integrates the many perspectives, including healthcare, that need to be considered when a disaster occurs (Smart Mature Resilience, 2018).

Arguably, to achieve a marriage of disaster management, disaster medicine and e-health, an integrated support system should be developed. In this paper, we report our work in progress towards the development of *disaster e-health support systems (*DEHSSs). We analyse the multidimensional nature of disaster e-health, founded on coordination, information and knowledge management, visualization, collaboration and communication, and describe the characteristics DEHSSs should have to support the definition and enactment of medical disaster response plans, both at training level and in actual incidents. Our goal is to define a roadmap for the development of tools that add value to current software infrastructures in different aspects like augmenting the situational awareness of responders, providing advanced diagnosis and triage utilities, covering the informational needs of medical responders, and eventually helping victims to keep calm and safe while helpers arrive to their place.

We first describe the landscape of disaster e-health in the context of knowledge management. Next, we sketch the requirements for embedding e-health applications in disaster preparation plans and outline the main topics to deal with on the way to DEHSSs. Some conclusions close the paper.

A MULTIDIMENSIONAL VIEW OF DISASTER E-HEALTH

Disaster e-health was defined in (Norris et al., 2016) as "*the application of information and e-health technologies in a disaster situation to restore and maintain the health of individuals to their pre-disaster levels"*. The "e-"prefix is key in the definition since it denotes extensive use of ICTs to build solutions aiming at improving the speed and quality of response as well as victim access and safety. These responses are performed by medical response teams, often in cooperation with other responders such as firefighters or police forces.

Hence, disaster e-health must be based on tools supporting the different stakeholders –including the victims themselves. Different authors have proposed multidimensional approaches to crises response (Canós et al., 2004; Comfort, 2007; Wolbers et al., 2017), and the use of specific technologies to support each dimension. Figure 1 shows the main dimensions that, in our view, disaster e-health tools should deal with. The principal support relates to the specification and monitoring of the intra- and inter- force *coordination* mechanisms that allows dispatching the right orders to the right actors at the right time, keeping process awareness to ensure full process coverage and avoid redundancy.

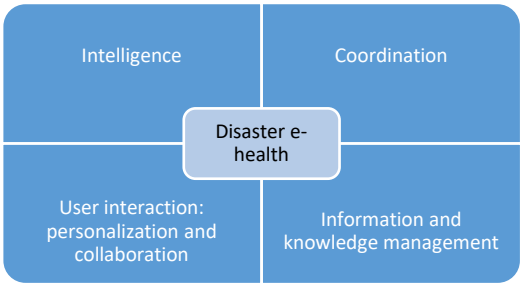

Figure 1. Dimensions of disaster e-health

The orders must be accompanied by the information required to perform each task to improve the e-health awareness and skills of disaster responders. The improvement must come from the inclusion of e-health knowledge in the disaster preparedness knowledge set. As pointed out by (Diniz et al., 2008), three basic types of knowledge affect disaster responses. First, tacit knowledge is in the minds of responders and is the result of years of experience in their work. Second, formal knowledge is the type of knowledge collected into a disaster plan, technical manuals, etc. Its sources are primarily the tacit knowledge that has been gathered in planning sessions, training exercises, etc., plus the result of engineering tasks, and other cross-disciplinary sources (e.g. maps and phone directories). Finally, the contextual knowledge emerges as first-responders (medical emergency services, public health authorities, law enforcement team, civil protection professionals, and others) respond to the disaster and provides "fresh" information about the situation of victims, properties, weather conditions, etc., constituting the so-called *context* of the situation.

The information provided to responders must be carefully selected to avoid overload and/or lack of information, which makes *customization* become another important issue. Moreover, in particularly complex cases, *collaborative decision making* can be also a requirement, as well as some type of decision support system. Last not least, the collection of high amounts of data from different types of sensors, especially those that monitor vital variables of persons, will require different types of intelligent (big) data processing tools.

EMBEDDING E-HEALTH APPLICATIONS IN DISASTER PREPARATION PLANS

Disaster response plans are the *cookbooks* where organizations of any type and size describe the procedures to respond to different types of adverse events. Plans include all the actions to perform in case of incidents, along with the information required by the actors involved in them. The plans serve also to define formal training exercises, as defined in (Taber et al., 2008), within the scope of the preparedness stage of the classical disaster management lifecycle. Depending on the size and type of organization, plans can be large textual documents whose elaboration spans for months or longer; moreover, they are difficult to disseminate among the different stakeholders since personalization is not one of the priorities of their designers. As a consequence, the command and control staff process the plan and generate the different instructions to the different responders.

Some authors have claimed that a broader view of disaster preparedness and response plans is required (Canós et al., 2004). Specifically, a shift towards interactive systems should significantly enhance the usability of disaster plans. Such an approach should take advantage of the numerous advances in software technology like process modelling and execution environments to cover the coordination dimension, data and application integration models to deal with the different types of knowledge, new interaction paradigms to provide customized interfaces, and so on. From this perspective, disaster plans would be a kind of processes or "*megaprograms*" (Wiederhold et al., 1990) that define the coordination of high-level modules to solve the complex problems presented by disaster response. Coordination would be specified as a process using some process modelling language, preferably with improvisation-supporting constructs (Dirr and Borges, 2016).

Disaster response plans aim primarily at avoiding life losses, so their procedures tend to prioritize the evacuation of people, paying little attention to the health status of victims and the interventions they require. In these cases, the speed, accessibility, and cost-effectiveness of e-health systems would be of great help for medical responders. Hence, e-health systems should be incorporated as additional modules of the megaprogram a disaster response plan is. Syntactic interoperability would allow the connection of e-health systems with the disaster management systems by defining the necessary interaction protocols. Additionally, the integration of heterogeneous e-health data into the context of the disaster will require semantic integration mechanisms based on ontologies. Last, but not least, privacy issues require special attention. In this regard, work in the so-called

Hippocratic Databases (Agrawal et al., 2002) can be very relevant.

It is well-known that poor inter-agency communication, particularly between emergency managers and clinicians, is a significant cause of sub-standard healthcare in disasters. One of the co-authors of this paper is developing a classification as a basis for a systematic approach to the development of systems that will re-engineer critical communication processes using information and e-health technologies (Abbas et al. In press). The objective of this approach is to specify and design a knowledge-based telehealth system based on the timely exchange of information contained in *minimum data sets* (MDSs) defined by inter-agency needs. The MDSs draw on data captured by sensors in real time and also contained in dynamic databases constructed from environmental, demographic, and clinical sources. The MDSs are assemblies of database records updated in real time and maintained by appropriate document management systems. Knowledge exchange by MDSs shares similar design characteristics - intelligent adaption to changing scenarios, presentation and management of information, and communication and collaboration- with research on multimedia emergency plans by another co-author of this paper (Canós et al., 2004). These two studies have the same overall goal, personnel safety, with complementary perspectives – the multimedia emergency plans are concerned with preventing injury, and the research on MSA focuses on providing rapid and appropriate healthcare when injury has occurred.

TOWARDS DISASTER E-HEALTH SUPPORT SYSTEMS

To make the benefits of disaster e-health tangible, DEHSSs should be designed and developed. In terms of global disaster response, a DEHSS would be the *view* of a larger disaster support system generated specifically for medical responders. Such a view would necessarily include editing facilities to allow disaster e-health experts to add as much formal knowledge as possible and define the coordination mechanisms that prescribe the right response to a particular incident. From all the formal knowledge, and possibly incorporating context, the system should be able to generate personalized action plans depending on the particular skills of each responder. In addition, self-care instructions and even psychological attention could be provided to victims waiting for their support to arrive. Finally, logging all the actions performed would be of great help during the *post-disaster* analysis of the responses.

Besides actual disasters, which would provide the *situated training* mentioned in (Taber et al., 2008), the functionality of DEHSSs would allow more formal training experiences. The possibility of defining disaster scenarios and enacting the corresponding responses, with their corresponding further evaluation, would certainly increase the capabilities of the medical response teams. Efforts are required in a number of research and development lines, where new solutions can be created from scratch or adapted from similar solutions in closely related fields, like:

- Document engineering tools for the efficient generation of personalized training and/or response plans.
- Process support technology to model and enact response procedures; support for improvisation must be among its main requirements.
- Library and information science principles to organize information in digital libraries accessible to the different components of DEHSSs.
- Big data analytics suites to process all the data received by wearable devices and sensors that help to improve situational awareness.
- Mapping and navigation software to generate safe evacuation paths to people affected by a disaster, as well as to help responders access to disabled victims. The development of map-driven mashups showing geo-tagged pieces of knowledge is undoubtedly convenient.
- Augmented reality interfaces that complement the aforementioned mashups, bringing e-health related information relative to victims like the electronic health record, vital signs, and so on.

The infrastructure supporting DEHSSs must principally be cloud-based since *flexibility* to support hundreds or thousands of requests per time unit is the key to make any solution viable. Therefore, the creation of government-owned private clouds raises new architectural challenges that are worth study.

CONCLUSION

In a disaster, the potential victims are the weakest link in the chain of assistance. In most cases, the lack of good training programs at schools and municipalities makes people to "*run towards where they see others run*"[2] as their primary reaction. In other cases, the willingness to support other victims can lack a clear objective sometimes leading to counter-indicated care. Additionally, when rescue forces get to where victims are, little information is provided about their health history, risking the application of wrong treatments. So far, the

[2] In words of J. M. Gil, a psychologist expert in disasters; informal talk.

emergency management research community has been much more focused on rescue tasks than in providing enhanced attention to the people.

Disaster e-health aims at filling the gap between people's needs and rescuers capacity of action in several ways. First, providing better situational awareness about the state and medical history of citizens affected by a disaster. Second, by increasing the knowledge available for medical responders. Third, by improving preparedness of both responders and citizens to drive first-minute responses which can save lives. And fourth, making disaster response go one step further by leading the medical dimension to the same level than others. The challenges are numerous, both at the conceptual and technological level. We expect that the development of DEHSSs will make real the potential that disaster e-health shows in the mid-term.

ACKNOWLEDGMENTS

The work of José H. Canós is funded by the Spanish MINECO under grant CALPE (TIN2015-68608-R). The authors gratefully acknowledge the award of grants to the DEH project from the Royal Society of New Zealand and the Auckland University of Technology.

REFERENCES

Abbas, R. and Norris, A. C. "Inter-Agency communication and information exchange in disaster healthcare", Paper submitted to *15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)*, Rochester, 2018.

Abbas, R. Norris, A. C., Parry, D. T. and Madanian, S. "Disaster e-Health and interagency communication in disaster healthcare: A suggested road map". *Proceedings of the Health Informatics New Zealand (HINZ) Annual Conference*, Auckland, 2016.

Agrawal, R., Kiernan, J., Srikant, R. and Xu, Y. "Hippocratic databases". *Proceedings of the 28th VLDB Conference*, Hong Kong, China, 2002

Bissell, R. A. (2007) "Public health and medicine in emergency management" (Ch. 16), in *Disciplines, Disasters and Emergency Management: The Convergence and Divergence of Concepts, Issues and Trends from the Research Literature*, D. A. McEntire, Ed. Springfield: Charles C Thomas, pp. 213-223.

Canós, J.H., Alonso, G. and Jaén, J. (2004). "A multimedia approach to the efficient implementation and use of emergency plans". *IEEE Multimedia*, 11(3): 106-110. DOI: 10.1109/MMUL.2004.2

Comfort, L. K. (2007). "Crisis management in hindsight: Cognition, communication, coordination, and control". *Public Administration Review*, 67(s1), 189-197.

Coiera, E. (2015) Guide to Health Informatics, 3rd ed. Boca Raton, FL, USA: CRC Press.

Dirr, B. and Borges, M. R. S. (2016) "Shaping procedures to deal with complex situations". *Proceedings of the 2016 IEEE International Conference on Systems, Man and Cybernetics*, pp.2151-2156.

Doarn, C. R. and Merrell, R. C. (2014) "Telemedicine and e-Health in Disaster Response", *Telemedicine and e-Health*, vol. 20, no. 7, p. 605.

Galea, S. (2007) "The long-term health consequences of disasters and mass traumas", *Canadian Medical Association Journal*, vol. 176, no. 9, pp. 1293-1294.

Hogan, D. E. and Burstein, J. L. (2016) Disaster Medicine, Philadelphia, PA, USA: Lippincott, Williams and Wilkins.

Hristidis, V., Chen, S.-C., Li, T., Luis, S., and Deng, Y. (2010) "Survey of data management and analysis in disaster situations". *Journal of Systems and Software*, vol. 83, no. 1, pp. 1701-1714.

James, J. J. and Walsh, L. (2011) "E-health in preparedness and response", *Disaster Med Public Health Prep*, vol. 5, pp. 257-258.

Norris, A. C. and Althwab, A. "The scope and development of disaster e-Health". *Proceedings of the Health Informatics New Zealand (HINZ) Annual Conference*, Rotorua, 2013.

Norris, A. C., Martinez, S., Labaka, L., Madanian, S., Parry, D. T. and Gonzalez, J. J. "Disaster e-Health: A new paradigm for collaborative healthcare in disasters". *Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2015)*, Kristiansand, 2015.

Rao, R. R., Eisenberg, J., and Schmitt, T. (2008) "Improving disaster management: The role of IT in mitigation in preparedness, response, and recovery". Washington D.C., USA: The National Academy Press.

Sakanushi, K. et al. (2013) “Electronic triage system for continuously monitoring casualties at disaster scenes”. *J Ambient Intell Human Comput*, vol. 4, pp. 547-558.

Smart Mature Resilience, Smart mature resilience for more resilient cities in Europe, Accessed 21 March 2018, http://smr-project.eu.

Subbarao, I. et al. (2008) “A Consensus-based educational framework and competency set for the discipline of disaster medicine and public health preparedness”. *Disaster Medicine and Public Health Preparedness*, vol. 2, no. 1, 2008, pp. 57-68.

Taber, N., Plumb, D., Jolemore, S. (2008) ""Grey" areas and "organized chaos" in emergency response". *Journal of Workplace Learning*, Vol. 20 Issue: 4, pp.272-285. DOI: 10.1108/13665620810871123

Wiederhold, G., Wegner, P. and Ceri, S. (1992). “Toward megaprogramming”. *Commun. ACM* 35, 11 (November 1992), 89-99.

Wolbers, J., Boersma, K., an dGroenewegen, P. (2017). Introducing a fragmentation perspective on coordination in crisis management. *Organization Studies*, DOI: 10.1177/0170840617717095