Environmental Modelling & Software 95 (2017) 180–195

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Modelling the complexity of the network of interactions in flood emergency management: The Lorca flash flood case

Raffaele Giordano [a,*], Alessandro Pagano [a], Irene Pluchinotta [b], Rosa Olivo del Amo [c], Sonia M. Hernandez [d], Eduardo S. Lafuente [d]

[a] Water Research Institute, National Research Council (CNR-IRSA), Via De Blasio, 5, 70132, Bari, Italy
[b] LAMSADE, CNRS UMR 7243, Université Paris Dauphine, Place du Maréchal de Lattre de Tassigny, 75016 Paris, France
[c] Typsa Group, Avda Juan Carlos I s/n, 30100 Espinardo, Murcia, Spain
[d] Confederacion Hidrografica del Segura, Comisaria de Aguas, Plaza Fontes, 1, 30001 Murcia, Spain

ARTICLE INFO

Article history:
Received 5 October 2016
Received in revised form
15 May 2017
Accepted 16 June 2017

Keywords:
Emergency management
Social network analysis
Participatory modelling
Problem structuring method
Flood risk

ABSTRACT

There is growing awareness that fast response to emergency situation requires effective coordination among several institutional and non-institutional actors. The most common approaches, based on innovating technologies for information collection and management, are not sufficient to cope with the increasing complexity of emergency management. This work demonstrates that effective cooperation claims for a shift from information management to interaction management. Therefore, methods and tools are required in order to better understand the complexity of the interactions taking place during an emergency, and to analyse the actual roles and responsibilities of the different actors. This paper details the design and implementation of an integrated approach aiming to unravel the complexity of the interaction network based on Storytelling, the Problem Structuring Method, and Social Network Analysis. The potential of the integrated approach has been investigated in the Lorca (Spain) flood risk management case study.

Software availability

Program name: *ORA-NetScenes
COPYRIGHT (c) 2001-2016: Kathleen M. Carley
Contact address: Center for Computational Analysis of Social and Organizational Systems (CASOS) Institute for Software Research (ISR), School of Computer Science - Carnegie Mellon University - 5000 Forbes Avenue Pittsburgh, PA 15213-3890
Creation year: 1995
Year available version: 2016
Version used: ORA 3.0.9.9.36 (June 2016)
Program language: Java GUI and C++ backend
Software availability: Permission to use this version of the software or any parts of it and to use, copy, or modify its documentation is hereby granted for research and teaching only purposes. Commercial and governmental licensing of the software is available by contacting Dr. Kathleen M. Carley (kathleen.carley@cs.cmu.edu).

Hardware Requirements
- CPU with 500 megahertz or higher processor clock speed recommended (3 Ghz is ecommended for large datasets) Intel Pentium/Celeron family, or AMD K6/Athlon/Duron family, or compatible processor recommended
- 512 MB of RAM or higher recommended (1 GB preferred)
- 500 MB of available hard disk space

1. Introduction

Over the last few years, a number of natural disasters have demonstrated the need for quick and effective responses, to minimize the number of deaths and injuries, as well as the financial cost associated with damage and losses (Luokkala and Virrantaus, 2014; O'Sullivan et al., 2013; Seppänen and Virrantaus, 2015). Response needs to be provided under the severe stress of crisis conditions,

* Corresponding author.
E-mail addresses: raffaele.giordano@cnr.it (R. Giordano), alessandro.pagano@ba.irsa.cnr.it (A. Pagano), irene.pluchinotta@dauphine.fr (I. Pluchinotta), rolivo@typsa.es (R.O. del Amo), sonia.hernandez@chsegura.es (S.M. Hernandez), eduardo.lafuente@chsegura.es (E.S. Lafuente).

http://dx.doi.org/10.1016/j.envsoft.2017.06.026

and requires the coordinated involvement of experts and organizations from several fields (Katuk et al., 2009). Nowadays, the response to crises becomes an emerging, large-scale, socio-technical system of individuals, groups, organizations and jurisdictions that need to coordinate their actions for delivering effective operations (Hardy and Comfort, 2015; O'Sullivan et al., 2013). No single entity has complete control of these multi-scale, distributed, highly interactive networks, or the ability to evaluate, monitor and manage emergencies in real time.

Enhancing the coordination effectiveness of different responders has been considered from multiple perspectives such as lack of cross-sectors structures, lack of common goals, lack of common concepts, lack of distribution of information, lack of trust, complex accountability issues, inequalities of power and struggles for dominance, legacy issues, different perception of the collaboration, and lack of situational awareness (e.g. Aldunate et al., 2005; Comfort, 1999; Danielsson and Ohlsson, 1999; Kapucu et al., 2009; Moynihan, 2008; Hardy and Comfort, 2015; McMaster and Baber, 2012; Seppänen et al., 2013). Most of these studies suggested that involved agencies claimed for a fast though-smooth and well-structured distributed and collaborative decision-making process (Brehmer, 1991; Cosgrave, 1996; Smith and Dowell, 2000). Nevertheless, the implementation of collaborative decision-making approaches (i.e. Hills, 2004; Raiffa, 2002; Turoff et al., 2008) has received limited attention (Kapucu and Garayev, 2011). This is mainly due to the existing gaps between the traditional emergency management methods characterized by centralization and hierarchy-based structures and the actual collaborative management process, characterized by non-hierarchical structure and flexibility (Kapucu and Garayev, 2011).

Furthermore, the capabilities of organizations to overcome the fractured nature of information in distributed system, through an effective information exchange by collaborative agents gained a lot of interest (Sorensen and Stanton, 2013; Comfort and Haase, 2006; Comfort, 1999). It is crucial that the right agents receive the right information at the right time (Calderon et al., 2014). Most of the efforts carried out for enhancing coordinated information management were meant to innovate the information technology for internal and external communication, information production and sharing (Luokkala and Virrantaus, 2014; Leskens et al., 2014). Several authors emphasize the inadequacy of these information management systems (Endsley et al., 2015; Leskens et al., 2014; Luokkala and Virrantaus, 2014; McMaster and Baber, 2012; Seppänen et al., 2013; Wolbers and Boersma, 2013). Firstly, these systems seem inadequate to cope with the dynamic nature of the emergency management process. Information management and sharing procedures within a responding organization and/or among different organizations might be jeopardized by the need to alter organization structure and roles, procedures and use of information in order to meet the demands of an exceptional event, such as an emergency situation (McMaster and Baber, 2012). Moreover, interaction networks change dramatically during an emergency leading to the creation of temporary multi-organization (Cherns and Bryant, 1984). The role of the different agents in the interaction network and the tasks they have to perform could change during a crisis. The existing emergency information management systems and the institutional protocols for information management in case of emergency seem to be incapable of adapting themselves to this changing interactional situation.

Secondly, evidences demonstrate that implementations of information management and communication technologies failed in many situations because of the oversimplification of the social processes at the base of emergency information management (McMaster and Baber, 2012). This has also been true for cases where innovative technology has been used (e.g. internet-of-things, smartphone, smart city cameras and stoplights, etc.). The key steps in the process of transforming risk information and warning into actions – i.e. hearing, understanding, believing, personalizing and deciding – are mediated through social structures. Exposing all individuals to the same information in the same way, without accounting for the different social structures, might affect the ability to generate novel ideas and interpretations of the emergency situation (Smart and Sycara, 2013; Leskens et al., 2014).

Effective cooperation for emergency management requires a shift from innovating information production and management technologies toward enhancing the interaction processes among actors involved in emergency management (Kapucu and Demiroz, 2017). Interaction represents the mechanism allowing the different actors to interpret their environment, to achieve a satisfactory shared understanding of the situation – i.e. sensemaking process (Wolbers and Boersma, 2013) – and to cope with the organizational and individual improvisation needed to deal with extreme events (Maitlis, 2005; McMaster and Baber, 2012). Enhancing the interaction among the different actors is a *sine-qua-non* condition to mitigate the conflicting interpretation of information about emergency due to differences in knowledge belief, customs and assumptions (Wolbers and Boersma, 2013), and to enable the knowledge processing and regenerating process, involving different teams and members of the same team with different background (Hardy and Comfort, 2015; Seppänen et al., 2013).

This work argues that a collaborative emergency management requires tools and methodologies capable of creating a decision-making environment in which parties are fully aware of their role and the roles of the others in the interaction space, according to the interdependency principle (Gray, 2004).

Emergency management network are more emergent than planned (Kapucu and Demiroz, 2017). This means that, although these networks are not completely independent from previously established relationships, they do not follow pre-emergency arrangements. Therefore, the analysis of the emergency management network cannot be based on existing and formalized relationships. Informal interactions are activated, and non-institutional actors play crucial roles in responding to the emergency. Keeping tracks of these interactions is difficult, hampering the capabilities of analysts and researcher to implement formal methods for the analysis of the interplay of factors influencing the network effectiveness – e.g. actors, knowledge, resources and tasks (Kapucu and Demiroz, 2017). Moreover, although existing quantitative methodologies, such as Social Network Analysis, offer conceptual and methodological tools for explaining macro-level structural patterns in the interaction networks (Schipper and Spekkink, 2015), the comprehension of the dynamic nature of the emergency management network cannot neglect the role of micro-level – i.e. agent level – behaviours.

In order to address the above mentioned issues, a methodology based on the integration among the Storytelling approach (Boyce, 1995; de Bruijn et al., 2016), Problem Structuring Methods (PSM) and Social Network Analysis (SNA) has been adopted. This work aims at demonstrating that the integration between SA and PSM allows integrating the macro- and the micro-level in analysing and unravelling the complexity of the emergency network. The central research question of this article is: to what extent the integration between the PSM capabilities to collect and structures individual behaviours, and SNA quantitative measures for describing the macro-properties of the network is suitable to support emergency managers in identifying barriers to the cooperation and collaboration (Bodin and Crona, 2009), and in defining potential improvements of the emergency management procedures? To this aim, this work evaluates the suitability of the PSM-SNA integrated