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Innovative Applications of O.R.

Application of the Viable System Model to analyse communications structures: A case study of disaster response in Japan

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ABSTRACT

Every year, natural and man-made disasters affect hundreds of thousands of people and cause extensive damage. OR has made substantial contributions to disaster response and these have been the subject of several recent literature reviews. However, these reviews have also identified research gaps for OR – two of which are (1) limited contribution from soft OR, and (2) a need to model communications during disasters where there are complex interactions between stakeholders. At the intersection of these gaps we apply the Viable System Model (VSM) to examine challenges of rapid communication viability during dynamic disasters. The data that informs this paper were collected in four case studies in Japan – three on its current capabilities (e.g. a local government disaster management office) and one on its response to a past disaster (the Great Hanshin-Awaji Earthquake in 1995). This paper shows how applying VSM identified generic gaps and opportunities for communication systems and shows how these case studies signal the utility of VSM structures to arranging communications for fast-paced and changing environments. This paper also contributes to VSM theory through developing two new concepts (1) environmental support mechanisms for viability; and (2) rapid implementation unit emergence.

1. Introduction

Natural, technological, social and health hazards risk affecting hundreds of thousands of people globally (Proske, 2008). In 2011, 325 disasters occurred across the world, killing around 35,000 people and causing economic damage of over US$370 billion (Swiss Reinsurance Company Ltd., 2012). For disaster response, the United Nations Foundation (2011, p. 10) recognises that "*good communication is essential to effective coordination*" but "*due to poorly adapted tools, training and strategies, responders are increasingly ill-prepared to produce useful knowledge from the flow of information and data*". For response agencies, individual responders and survivors, information is a critical resource necessary to facilitate life-saving operations (Comfort, 1996). However, disasters are dynamic and their constantly changing landscape makes effective communications between such stakeholders difficult.

Communication flow during disaster response can be a messy problem (Ackoff, 1981) as it requires the rapid search, exchange and absorption of information being transmitted through networks of organisations (Comfort & Kapucu, 2006) involving people from different organisations who may never have worked together (van de Walle & Turoff, 2008) working in dynamic situations with high levels of uncertainty and complexity (Argote, 1982). In these settings, information flow is the central nervous system (Knuth, 1999) but co-ordinating this in large-scale disasters involving multiple agencies is one of the least understood problems in public management (Comfort & Kapucu, 2006). While research has explored poor information sharing between organisations during response (e.g. Dawes, Creswell, & Cahan, 2004; McEntire, 2002), Bharosa, Lee, and Janssen (2010) claim there is still a scarcity of studies with little empirical data being available.

Applying OR techniques to analyse knowledge and information flow is well established (for an overview see Edwards, Ababneh, Hall, & Shaw, 2009), but applications to fast-paced disasters are limited. OR's potential for this application is advocated by Simpson and Hancock (2009) and Altay and Green (2006) – the same authors who observe the limited application of soft OR techniques to disasters (like Galindo & Batta, 2013). Here we locate the research opportunity and the objectives of this paper: the Viable System Model (VSM) (Beer, 1979, 1981,1985) is a soft OR method capable of modelling communication structures and diagnosing failures of system configuration that would compromise information flow (Flood & Jackson, 1991). The first objective is to explore and extend the VSM as an approach

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to analyse contexts of complex communication, where there are key uncertainties, multiple actors and conflicting views (Mingers & Rosenhead, 2004). The second objective is to develop understanding of VSM capacity to structure and analyse communication in fast-paced disasters. The third objective is to contribute to the collection of case studies of applying soft OR techniques (Ormerod, 1995, 1998,1999).

This paper first examines the literature to explore OR's fit for analysing disaster response communication. We then apply the VSM to analyse data collected from Japan regarding their current response capabilities and their response to a past disaster – the Great Hanshin-Awaji Earthquake in 1995. We conclude with discussions of both the utility of analysing disaster response using VSM and generic theoretical issues around communication during such events.

2. OR techniques

OR has made a substantial contribution to disaster research (Altay & Green, 2006; Galindo & Batta, 2013; Green & Kolesar, 2004; Simpson & Hancock, 2009) by applying a wide range of analytical techniques to bear on the myriad of complex challenges created by disasters. For example, systems dynamics has been used to analyse disaster relief supply chains (Peng, Peng, & Chen, 2014), multi-commodity network flow modelling has been applied to route emergency vehicles (Özdamar, Ekinci, & Küçükyazici, 2004), and agent based simulation was used to model the dissemination of a disaster warning message (Nagarajan, Shaw, & Albores, 2012). Other studies include, sample-path methods and stochastic dynamic programming being used to build a prioritisation model for mass-casualties (Jacobson, Argon, & Ziya, 2012), multi-objective optimisation models informing the development of disaster plans (Hu & Mehrotra, 2012), a multi-criteria approach for trade-offs between system robustness and recovery speed for multiple related disaster events (Zobel & Khansa, 2014) and multi-agent optimisation being applied to responding to earthquakes (Edrissi, Poorzahedy, Nassiri, & Nourinejad, 2013). The diversity of studies continues, for example: location algorithms aided analyses of pre-positioning disaster provisions (Campbell & Jones, 2011), dynamic decision tree application for developing city resilience (Ciumasu, 2013), boolean and stochastic programming applied to service levels for earthquake response (Lejeune, 2013), Monte-Carlo simulation modelling to understand behavioural response to landslides (Uchida, 2012) and a deterministic model built for resource scheduling following an H1N1 outbreak (Rachaniotis, Dasaklis, & Pappis, 2012). On OR applied to disaster communications, the literature is less prolific – one study by Eiselt and Marianov (2012) applies mixed integer programming to analyse mobile phone signal availability after disasters.

Common across these OR studies is the application of reductionist approaches that narrow on key variables at the expense of their wider interdependencies/context. Unless carefully applied, such approaches could overlook the need for holism in risk and communication analysis (Haimes, 2012, p. 1455). Comfort (1996, p. 4) reiterates the need for holism in modelling disaster environments, stating they need "*modeling that can capture the continuously evolving relationships among the interdependent components of the system*". Such complex interrelationships arise from the dynamic environment of information rapidly flowing across responders' organisational structures facilitated by individual/agency relationships and moderated by misinformation and misinterpretation. Systems thinking is ideally suited to exploring such complexities (see Mingers & White, 2010 for an overview).

Systems thinking posits that emergent properties exist in systems and these cannot be understood by examining only individual parts (von Bertalanffy, 1968). Rejecting reductionism, systems thinking advocates holism to analyse relationships between parts to uncover emergent properties (Jackson, 2000) – for example, to qualitatively appreciate system deficiencies and the efficacy of potential resolutions (Shaw & Blundell, 2010). In choosing a method to analyse features and diagnose deficiencies in disaster communication structures, several systems thinking approaches are available – whether they be interpretive, emancipatory, postmodern or functionalist (see Jackson, 2000). Of the two main types evident in the literature, interpretive methods build understanding by accommodating multiple perspectives (such as soft systems methodology (Checkland & Scholes, 1990)), and functionalist approaches allow analysts to objectify system characteristics (such as viable system modelling (Beer, 1979)).

Our context of a disaster response communication system includes all agencies/individuals that have responsibility to perform a function in responding to a disaster (e.g. search and rescue, command and control, multi-agency coordination). Each function generates situational knowledge which needs to be shared across functions for more effective response. By focussing on functions and their structural capability to communicate effectively, we require a method to analyse and diagnose communication faults across functions – a functionalist analytical method. VSM is a functionalist method to explore communication through analysing "*information flows and communications links*" (Flood & Jackson, 1991, p. 92). It was chosen as an analytical method in this research because it, unlike every other systems thinking approach, provides analysts with a structure for analysing explicit communication channels exploring detailed relationships between functions in the system and so it is ideally suited to this context. Also, as VSM takes a functionalist approach, it can explore the threats/consequences for response if functions do not communicate effectively as well as identify structural reasons for such failures.

3. VSM

This section introduces the concepts and analytical structures of VSM, providing a level of detail sufficient to understand the remainder of this paper. For more detailed accounts, see Beer (1979, 1981,1985), Yolles (2005), Schwaninger (2006) and Espejo and Gill (1997).

The VSM was developed by Beer (1979) and specifies that five functions are needed in a system to ensure its 'viability'. Viability was defined by Beer (1979) to mean existence but later interpretations suggest that viability is more concerned with effectiveness (Yolles, 2005) which is more appropriate here. Underpinning the theory is that the effectiveness of a system is compromised if the VSM structure is not completely adhered to (Schwaninger, 2006). From Espejo and Gill (1997), the five functions making up the VSM structure are:

1. *Implementation (also known as 'System 1' (S1) in VSM)* – performs the tasks to accomplish system goals e.g. urban search and rescue (USAR) teams who look for disaster victims.
2. *Co-ordination (S2)* – ensures synergy to perform implementations e.g. ensures USAR teams complement each other's work.
3. *Control (S3)* – monitors implementations and operations to maintain efficiency and allocate resources as well as audit performance e.g. operational command of particular implementation teams.
4. *Intelligence (S4)* – develops strategic options for the system to adapt to its environment e.g. analysing secondary threats from the disaster.
5. *Policy (S5)* – sets the overall direction of the system e.g. strategic command of the disaster response.

These functions (S1–S5) are represented in Fig. 1, with lines depicting the communication channels between them/the environment. The dotted communication channel in Fig. 1 carries what is called the algedonic signal, which enables implementation to alert policy directly to issues requiring urgent attention (Beer, 1985). The two thick grey arrows in Fig. 1 show an important relationship between control and intelligence. Policy must ensure this relationship is balanced (through what VSM calls a homeostat) to ensure that control and intelligence are providing equal weight to the policy-making process. As discussed below, imbalances here can cause problems. Another feature of VSM is recursion, which stipulates that each system is "*embedded in other more comprehensive*