A System Dynamics Model of the 2005 Hatlestad Slide Emergency Management

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ABSTRACT

It has long been recognized that the management of emergencies requires that response organisations act flexibly, becoming an "emergent organisation" to better manage the fact that disasters do not follow scripts. Nevertheless, recent research shows that crisis response organisations prefer to follow patterns adequate for normal situations. Arguably, the resistance to become an emergent organisation could be related to poor understanding of how to move from disorganisation to self-organisation. We extend a recent system dynamics work by Tu, Wang and Tseng, describing the transition from disorganisation to self-organisation in the Palau case, to analyse the management of disorganisation in the fatal Hatlestad landslide in Norway. We suggest that the causal structure of the system dynamics model describing the Palau and the Hatlestad case should be considered a candidate for an emergent "middle-range theory" describing the management of disorganisation in emergencies. We propose specific data collection to test the candidate theory.

Keywords

Emergency management, management of disorganisation, emergent organisations, theory building, system dynamics

INTRODUCTION

Long ago, Dynes and Quarantelly (1976) pointed out from a compilation of 36 studies published 1957-1973 that organisations trying to hold on to traditional plans and procedures run into problems when an emergency occurs and do a worse job at responding than those who move to greater flexibility or resiliency. Despite this early and well-known insight, a recent study based on questionnaire responses from an international sample of emergency managers shows that "response organisations prefer to follow the general protocols of communication set-up for normal situations also in the event of a crisis" (Palttala, Boano, Lund and Vos, 2012, p. 5).

Crisis management is extremely complex, even becoming increasingly more complex (Boin and Hart, 2008). Several theory-based approaches haven used and new approaches are emerging. Gilpin and Murphy (2008) argue that the contingency, uncertainty, and happenstance; the unexpected confluence of unrelated events; and the destabilizing influence of rapidly changing circumstances are central factors in complex crises. Hence, an approach is needed that "maintains a vision of the changeable and complex nature of crises, and it looks for ways to operate within that very real-world environment of confusion, unforeseen events, and missing information." (Gilpin et al., 2008, p. 4) Accordingly, complexity theory, "the study of interaction processes within complex systems, including social systems such as organisations" (Gilpin et al., 2008, p. 6) must play a central role to advance our understanding of crisis management.

Gilpin and Murphy are not the only proponents of an approach based on complexity theory. Other recent research implies that crisis operations need to be “multi-organisational, trans-jurisdictional, polycentric response networks.” They demand lateral collaboration and coordination, not top-down command and control (Hart, Boin, Stern and Sundelius, 2005, p. 147).

Simpson and Hancock (2009) point out that most past work on emergency response has addressed well-structured problems of emergency services. Such studies assumed implicitly that an “Established” organisation (Dynes et al., 1976) responds based on detailed planning. However, disasters tend to disrupt plans and impair the very same organisation in charge of the emergency response. Simpson and Hancock analyse future research opportunities and conclude that “a single thread unites the particular areas of research opportunities discussed earlier in the paper: each is a problem of working in a disorganized environment” (Simpson et al., 2009, p. S136). They go as far as characterizing management of disorganisation as an important operational research growth area for the next 50 years. (Simpson et al., 2009, p. S126)

The case for a new approach based on complexity theory is strong. However, complexity theory is a vision involving many and intricate aspects related to interaction, holism, emergence and chaos (Byrne, 1998). Related concepts are self-organisation, complex adaptive systems, and co-evolution. Complexity theory attempts a generic, overall explanation of a whole range of phenomena – it is a *general theory* (in the sense of Schwaninger and Grösser, 2008, p. 450).

How to apply the theory of complexity to the organisational behaviour in emergencies has been little studied. In particular, computable models of crisis and emergency management using complexity theory are virtually absent. One needs a specific theory that link observables leading to models and simulations that can be compared to the behaviour of real cases. In other words, a *middle-range theory* must be found. Quoting Merton’s definition (1968, p. 39) of middle-range theories : “theories that lie between the minor but necessary working hypotheses that evolve in abundance during day-to-day research and the all-inclusive systematic efforts to develop a unified theory that will explain all the observed uniformities of social behaviour, social organisation and social change”.

System dynamics modelling is colloquially characterized by the system dynamics community as ‘theory building’. Schwaninger and Grösser (2008) studied whether system dynamics enables the construction of high-quality theories. They provided strong evidence for that using a set of criteria for high-quality theories on a revelatory case (in the sense of Yin, 2009, p. 45ff). By analogy, the process of system dynamics modelling, as proposed in major text books (Richardson and Pugh, 1981; Sterman, 2000; Maani and Cavana, 2007) and as practiced in high quality research work satisfies the denomination of theory building.

A recent article in the prestigious System Dynamics Review (Tu, Wang and Tseng, 2009) applies complexity theory, in the sense of describing the emergence of order in dynamic nonlinear systems, to develop a system dynamics model of a the handling of a minor crisis – the Palau incident. The crisis is described and analysed in the book “Cognition in the Wild” (Hutchins, 1995). Hutchins data collection was performed on the vessel ”Palau”, on a four-day journey. On the last entry to the port the ship lost its power, and all electrical systems shut down. The navigation crew guided Palau into port despite the malfunctioning equipment. The crew had to operate on the verge of chaos, responding continuously to navigational cues obtained by calculating the ships position manually based on landmarks.

The Palau incident was a minor crisis, but it does share important characteristics with major crises and emergencies. Tu et al. argue that the handling of the Palau incident followed a common set of related events, disequilibrium–experimenting–emergence process as described by MacIntosh and MacLean (1999). This disequilibrium-experimenting-emergence process rhymes quite well with the empirically founded principle that successful handling of emergencies requires that the organisation transitions to an Emergent organisation (Dynes et al., 1976; Turoff, Gonzalez, Hiltz and Van de Walle, 2012).

Tu et al.’s system dynamics model can be seen as a middle-range theory for the Palau incident. The authors show that the model renders the reference behaviour of the emergency management as derived from the analysis provided by Hutchins (1995) and satisfies the canonical verification and validation principles of best-practice system dynamics modelling. Thus Tu et al’s work satisfies the criteria proposed by Schwaninger and Grösser (2008). In fact, Tu et al.’s work satisfies also this requirement : “For a theory what is required is a model along with a plausible account of why the model produces the behaviour that it does” (Lane, 2008).

In this paper we show that Tu et al’s work can be adapted to describe the handling of a real emergency. To this effect we searched the literature for studies of emergency response, hoping to find a well-documented case of an emergency that shared generic characteristics with the Palau incident (expressed in terms of a simple disequilibrium-experimenting-emergence process). We argue in next section that the Hatlestad slide is such a revelatory case. In the sections thereafter we develop a system dynamics model for the Hatlestad slide. First, drawing on a master thesis (Lango, 2010a), a working paper (Lango, 2010b), and a book chapter (Lango, 2011)[1] we describe the timeline of the Hatlestad slide emergency. Second, we estimate the number of first responders along the timeline. Third, using the same sources as for the timeline and the first responders (Lango, ibid) we derive reference behaviour modes for key variables in a system dynamics model of the Hatlestad slide and show that the reference behaviour is consistent with the disequilibrium–experimenting–emergence process (MacIntosh et al., 1999). Fourth, we present a high-level view of a candidate system dynamics model, which in terms of its causal structure is an extension of Tu et al.'s model to accommodate a variable number of first responders. Fifth, we show that the model is able to simulate the reference behaviour, and we examine the robustness of the model. Sixth, we conduct a feedback analysis to gain insight on the dynamics of the Hatlestad slide emergency. In the final section we argue that the system dynamics model of this paper qualifies as a candidate for a middle-range theory of the management of the Hatlestad slide. Further, we propose that the system dynamics model should be considered a rudimentary theory of emergency management and we suggest activities and research to collect data on management of emergency cases so as to critically test the ability of the model to describe a disequilibrium-experimenting-emergence process in emergencies.

THE HATLESTAD SLIDE

Hatlestad Terrasse is a neighbourhood in the city of Bergen, Norway, consisting of housing units in a rural hilly setting. In the early morning of 14 September 2005 the cliff above the neighbourhood broke apart, and a slide of clay, mud and rock hit a row of four houses while their residents were asleep. The slide went through the ground floors without causing the houses to collapse. People on higher floors were not harmed, and they could evacuate without need of assistance through windows in the first floors. But the residents in the ground floors were severely afflicted: ten people were buried and three died as a result, while seven more persons were wounded. A total of 225 people in the Hatlestad surroundings were evacuated (Wikipedia, 2007).

The disaster investigation pointed to extreme weather conditions in combination with the steepness of the hill behind Hatlestad Terrasse as a major cause of the landslide (Multiconsult AS, 2005). For several weeks before the disaster Western Norway experienced record-breaking precipitation. One weather station, Bergen-Florida, recorded the highest ever precipitation (156.5 mm/day during the fatal day of 14 September 2005) since the establishment of the weather station in 1875.

The Hatlestad slide was an agenda-setting crisis (Lango, 2010a, p. 91; Hart, Boin and McConnell, 2008, p. 19). Before the slide, policies for housing construction on hills did not require previous surveillance for landslide risk. The Hatlestad tragedy and several other slides in Western Norway in 2005 were extensively covered in the media and had a strong impact on public opinion, so that the policies for housing construction on hills became very strict. Also, preparedness toward extreme weather changed. After the Hatlestad slide, evacuation of citizens at risk is routinely considered in conditions of extreme weather. Other preventative measures were implemented, so for example the city of Bergen, which mapped out housing potentially at risk in case of extreme weather. (Wikipedia, 2007). For our work the relevance of the Hatlestad slide derives from the fact that the emergency has been thoroughly documented and that the facts make it a promising case to use for a natural extension of Tu el al.'s work on the Palau incident.

TIMELINE OF THE HATLESTAD SLIDE EMERGENCY

We describe the main events of the Hatlestad slide emergency as a first step to identify the behaviour over time of key variables of the simulation model (see section "Reference Behaviour Of The Hatlestad Slide Emergency" on p. 662).

"The 14th September 2005 at 1:54 am the Bergen fire department received a message about a landslide in Hatlestad-terrace. The fire department notified the [regional] Hordaland police department, Bergen municipality emergency response team and the Civil Defence. The National Guard offered their assistance. Neither voluntary organisations nor the County governor were informed at this stage". (Lango, 2010a, p. 60; Lango, 2011, p. 219ff) The urgent phase of the operation ended at 12:00 noon – that is, about 10 hours after the occurrence of the landslide. (Lango, 2010a, p. 60)

The table below shows the timeline of the Hatlestad slide emergency handling.

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[1] All work by Lango referenced in this paper is in Norwegian. The translation of the quotes from Norwegian to English is our own.

01:54	The Bergen fire department is alerted about the slide
01:58	The Bergen police is alerted
02:02	The Emergency Medical Services (EMS) receive a request of medical personnel
02:05	The police arrives at the disaster location
02:20	The air ambulance with a MD arrives at the disaster location
02:20	The Civil Defence arrives at the disaster location
03:00	The Bergen city management officer on duty is informed about the disaster
03:05	People are evacuated and transported away from the disaster area
03:28	The National Guard contact the police and report about their available manpower
03:30	Buses with the evacuated citizens arrived at Bergen Airport Hotel
04:00	The National Guard staff arrives at the disaster area
04:44	A geologist arrives at the disaster location
05:40	The police establishes an emergency team for the victims' families at Bergen Airport Hotel
06:15	The emergency team arrives at Bergen Airport Hotel
10:00	Bergen city establishes a crisis team
10:00-12:00	The fire department staff leaves the disaster location gradually after all the reported missed people were found
12:00	The urgent phase of the operation was ended

Table 1 The Emergency Management Timeline (Adapted from Lango, 2010a, p. 60)

ESTIMATED NUMBER OF RESPONDERS

The number of responders on site is a key variable for the simulation model. While the emergency handling crew in the Palau case was the same throughout the emergency, the responders to the Hatlestad slide emergency came in batches to the disaster site. Table 2 displays the number of first responders along hour of the events and the time computed relative to the arrival of the first rescue teams. The arrival time of the first rescue teams, 2:05 am, is the start of the handling of emergency on site. We make this the start of the simulation time (time zero).

Absolute time [hour]	Relative time [min]	Keyword	Arriving manpower [persons]	Total manpower [persons]	Reference
01:54		Start of emergency	0	0	(Lango, 2010a, p. 60)
02:05	0	Police squad arrived (12 policemen) Fire department arrived (18 fire fighters)	30	30	(Lango, 2010a, p. 63) Personal communication[2]
02:20	15	Air ambulance with MP Ambulance arrived (12 cars with 3 persons per ambulance) Civil Defence arrived More fire squads	1 36 35 12	114	(Lango, 2010a, p. 63-64) Personal communication[3] Estimate[4]

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[2] Personal communication from Peter Lango

[3] According to Peter Lango the number of Civil Defence staff was 30-40

[4] Estimate provided by Peter Lango based on knowledge about the fire brigades in Os and Sotra, which lie farther apart from Hatlestad Terrasse.

04:00	115	The National Guard arrived	18	132	Estimate[5]
10:00	475	The fire fighters start leaving the area		132	(Lango, 2010a, p. 60)
12:00	595	All fire fighters have left and the urgent phase finishes		102	(Lango, 2010a, p. 60)

Table 2 Overview of the estimated number of responders

REFERENCE BEHAVIOUR OF THE HATLESTAD SLIDE EMERGENCY

As in Tu et al.'s model of the Palau case, the system dynamics model for the Hatlestad slide emergency attempts to reproduce the reference behaviour for some key "soft" variables: the team's cognitive load, the mutual understanding, and the local innovations and changes instrumental for the transition to an "emergent" organisation. By 'local innovation and changes' we mean improvisations, i.e., departures from traditional plans and procedures – cf. p. 1 in relation to the findings by Dynes et al. (1976).

Also, as in Tu et al.'s study we generate the qualitative reference behaviour from descriptive sources using one's best judgment. Often, critical data needed of decision making is soft, such as morale, motivation or degree of mutual understanding. Those "soft variables", for which numerical metrics and data are not available, play a huge role in practice, but many modellers ignore them and restrict themselves to build models with "hard" variables, which rely on numerical metrics and can be measured with comfortable accuracy. But, as Forrester pointed out: "To omit such [soft] variables is equivalent to saying they have zero effect – probably the only value that is known to be wrong!" (Forrester, 1961, p. 57). Hence, soft variables that play a relevant role in the problem in question should be part of the model and they should be estimated using one's best judgment. The evaluation of the sensitivity of the simulation results to the uncertainty incurred is the required safeguard (Sterman, 2000, p. 854). Another point to keep in mind is that some important hard variables of today have a past as soft variables. E.g., the bodily awareness of hot and cold was the starting point for the concept of temperature. The first instruments used to measure temperatures, the thermoscopes, lacking a temperature scale could only indicate changes in temperature and were extremely inaccurate. Their successors, thermometers with a rough temperature scale, were still very inaccurate, owing to the lack of knowledge of fixed points for the calibration and to the ignorance of the effects of atmospheric pressure (Bolton, 1900; Middleton, 1966). However, the history of science repeatedly shows that even quite inaccurate measurements can do service to science by leading to insights that allow the improvement of measuring devices. For the thermometer, the rescue came with the gas thermometer which does have a quite accurate linear scale, since gases expand with temperature following a linear expansion law (the Boyle-Mariotte law). The Boyle-Mariotte law, derived from experiments with inaccurate thermometers, was discovered around 100 years after the invention of the first thermometer prototypes.

For the Hatlestad slide we use a relative scale in the range zero to unity for the key variables *Cognitive Load*, *Local Innovation and Changes* and mutual understanding *MU*. E.g., for *Cognitive Load* zero would be the minimum and unity would be the maximum cognitive load that could conceivable occur. The variables should be understood as referring to an average across the rescue team. The quality of the emergency management was deemed as "high" in four out of five criteria (recognition of the occurrence of the disaster, decision making, relation to media, termination of the rescue operation) and "middle/low" with regard to organisation/-coordination, which required a significant amount of improvisation (Lango, 2010a, p. 74). Hence we assume large variations in the improvisation (represented by the variable *Local Innovation and Changes*) during the emergency, while we assume smaller variations for *Cognitive Load* and mutual understanding (*MU*).

One might raise objections against anticipating the use of a metric for *Cognitive Load*, *Local Innovations and Changes* and *Mutual Understanding* in the absence of a more proper or more exact measurement method. Referring again to the invention of the thermometer, "strange as it may seem, the idea of a scale of temperature was familiar to physicians before they had any instrument to measure it with" (Middleton, 1966, p. 3). Quoting Sterman (2000, p. 854): "Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values".

It is important to keep in mind that our target goes beyond a faithful, quantitative reproduction of the reference behaviour given on Figure 1. Rather, our aim is to test the causal structure of the model – understood as a middle-range theory for the management of an expanding class of crises (first Palau, than Hatlestad), by 1) analysing the simulation model's ability to describe qualitatively the reference behaviour and 2) the robustness

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[5] There is no data on the National Guard staff. The number used is a rough guess

of the model.

“The most chaotic period were the first two hours of the operation” and “around 4 am the rescue operations went quite well” (Lango, 2011, p. 220). We assume that *Cognitive Load* starts to increase when the police and the first fire squad face a chaotic situation upon their arrival at the disaster site, that is, at 2:05 am or relative time zero min. At time 15 min when further 82 rescuers arrive we can assume that the cognitive load increases even more (Table 2). Around 4 am (relative time 115 min) the disaster site was under control, the workflow was smooth and there were enough resources and personnel (Lango, 2010a, p. 65). Accordingly *Cognitive Load* decreases rapidly and by relative time 115 min is near to its normal value. Since 18 members of the National Guard arrived at the disaster site at 4 am we assume that the (average) cognitive load reached its normal level for routine rescue tasks – arbitrarily defined as 0.75 in the normalized scale [0, 1] – after the National Guard had found its role in the rescue work, approximately half an hour after their arrival. The solid line labelled “1” in Figure 1 displays the qualitative reference behaviour for *Cognitive Load*.

The rescue team put significant effort to manage disorganisation by improvising and achieving self-organisation (Lango, 2010, p. 49, 74, 91, 100). We may assume that *Local Innovations and Changes* quickly increased upon the first responders’ arrival on the disaster scene while it has been reported that around 4 am the situation was under control (Lango, 2010, p. 65). The dotted line labelled “2” in Figure 1 displays the qualitative reference behaviour for *Local Innovations and Changes*.

Finally, the communication between the emergency services was good in the beginning (Lango, 2010a, p. 67), which we interpret as a high degree of mutual understanding (*MU*). We even assume that the mutual understanding is very high immediately upon arrival on the disaster site, until the communication difficulties impaired the understanding: “The emergency staffs worked well on the disaster site, but lacked the overview of what the others were doing, and their access to resources.” (Lango, 2010a, p. 14). Problems with the communication equipment were reported, owing to the high degree of humidity and the problems were compounded during the early morning hours, owing to darkness (Lango, 2010a, p. 66ff). We assume a sharp drop in mutual understanding with an increase later with the arrival of daylight, and because the situation gradually came under control with a marked improvement around 4 am (Lango, 2011, p. 220). The stippled line labelled “3” in Figure 1 displays the qualitative reference behaviour for mutual understanding (*MU*).

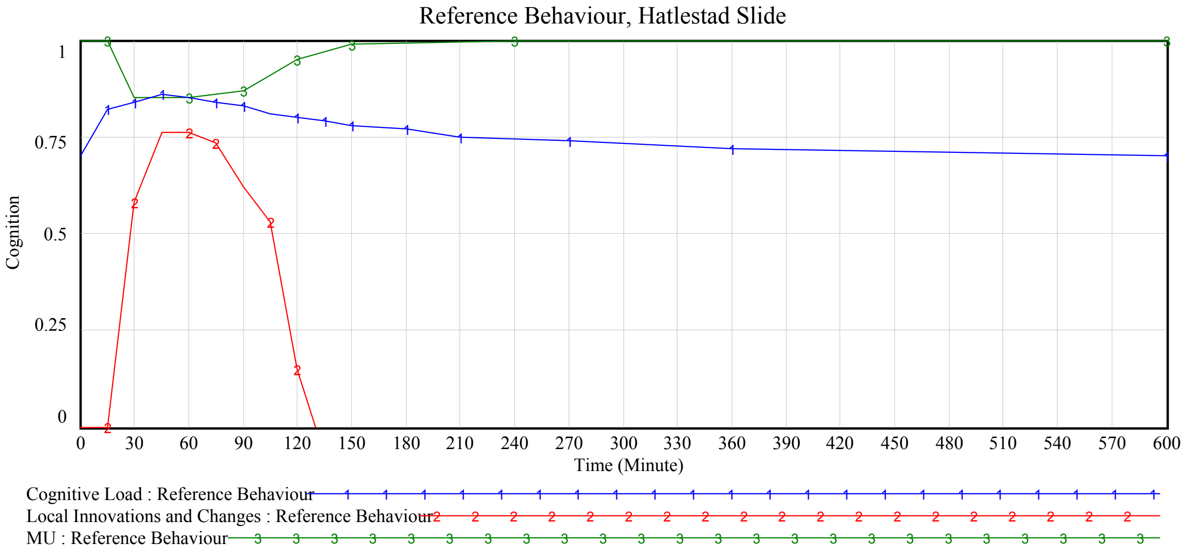

Figure 1 Reference Behaviour for the Hatlestad Slide (*MU* stands for mutual understanding). The data is mostly soft and inaccurate, but some aspects, such as when the curves rise or fall and the extrema occur, are reasonably accurate.

SYSTEM DYNAMICS MODEL

To the best of our knowledge the work by Tu el al. (2009) is the first study of the transition from disorganisation to self-organisation using system dynamics. Replication is extremely important to science (Jasny, Chin, Chong and Vignieri, 2011), but replication studies in social and management sciences were rarely done (Sterman, 2000, p. 855ff) and probably they are still rare. Since Tu et al.‘s framework is a candidate for a middle-range theory and a potential instrument for studying emergency management, we started with a replication study.

The details of our replication study of Tu el al.’s work will be found in Qian, Gonzalez, Bøe and Johansen (2013). For the purpose of this paper it is sufficient to summarize our main findings:

1. We were able to develop a Vensim model having the same feedback loops identified by Tu el al. as drivers of the simulated behaviour for the Palau case.
2. Our Vensim model, which was significantly smaller (50 variables vs 80 in Tu et al.'s model[6]), basically reproduced the results of Tu et al.'s study.

The numerical discrepancies between the simulation behaviour of Tu et al's model and our smaller Vensim model being very small, we opt for using our smaller and simpler Vensim model as starting point for our study of the Hatlestad emergency. For the purpose of this paper it is sufficient to describe the model in terms of its causal loop structure (Figure 2). We refer to an standard text on system dynamics (such as Sterman, 2000) for an explanation of causal diagramming.

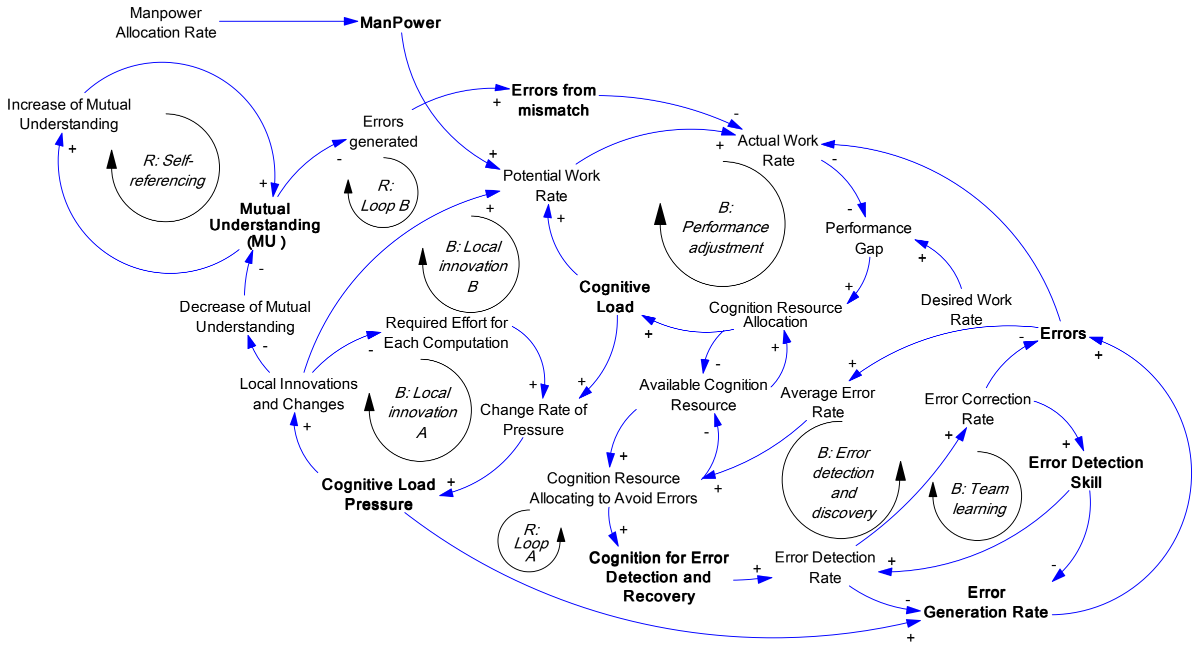

Figure 2 Causal loop structure of the simulation model. Box variables represent levels in the model.

The causal structure shown on Figure 2 is very similar to the structure given on Figure 10 of Tu et al.'s work (2009). The main difference is the introduction of varying manpower handling the emergency (*Responders*, *Responders Allocation Rate*). The introduction of responders, however, does not introduce more feedback loops, since the *Responders Allocation Rate* is exogenous (given by the column "Arriving manpower" in Table 2 on p. 662.) Note that in contrast to Tu el al. we have chosen not to display some variables in boxes (which would be a hint that they are so-called stocks in the system dynamics parlance). To facilitate the comparison with Figure 10 of Tu et al. we have shown the stock variables in bold face.

SIMULATION AND FEEDBACK ANALYSIS

The results for a simulation with parameters found with Vensim's calibration optimization are rendered below. For full details about the model, the simulation, including calibration and sensitivity analysis see Gonzalez and Ying (2013). Figure 3 shows that the agreement between the simulated behaviour and the reference behaviour for *Cognitive Load* is quite good for the first 300 minutes of the emergency handling. Afterward, the simulation model contradicts the reference behaviour, which assumed that the cognitive load would become equal to the normal load (arbitrarily given the value 0.7). The simulated behaviour, which on reflection makes better sense than the reference behaviour, shows that the cognitive load stays on a marked higher level than under normal (routine) rescue operation circumstances. Figs. 4-5 show the results for *Local Innovations and Changes* and for *Mutual Understanding (MU)*. All in all, the simulation model agrees reasonably well with the reference behaviour as qualitatively inferred from the literature.

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[6] The corresponding author in Tu et al.'s work, Ya-tsai Tseng, kindly provided us with their simulation model, which was developed with the simulation tool *ithink*.

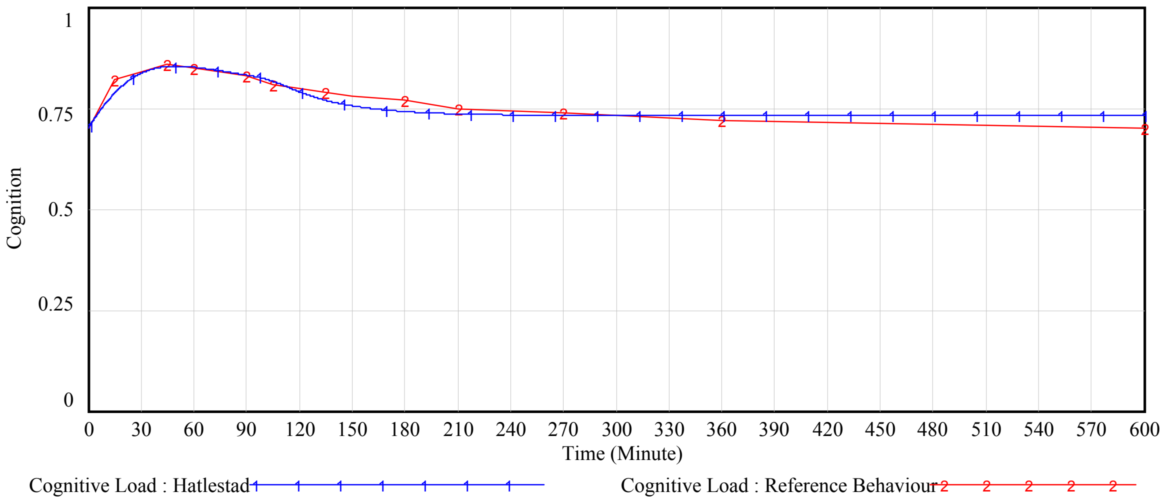

Figure 3 Comparison of simulated (1) vs reference (2) behaviour for *Cognitive Load*

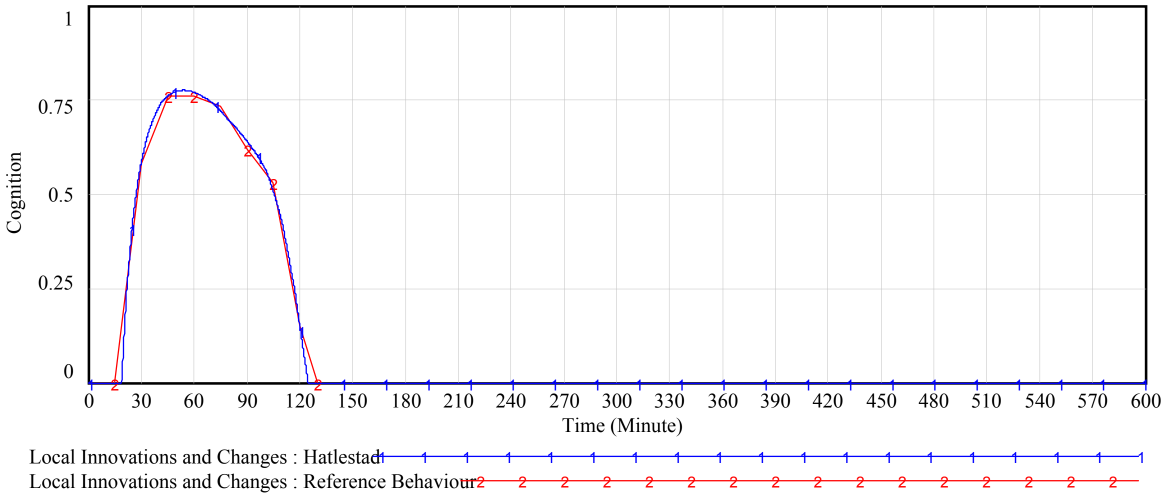

Figure 4 Comparison of simulated (1) vs reference (2) behaviour for *Local Innovations and Changes*

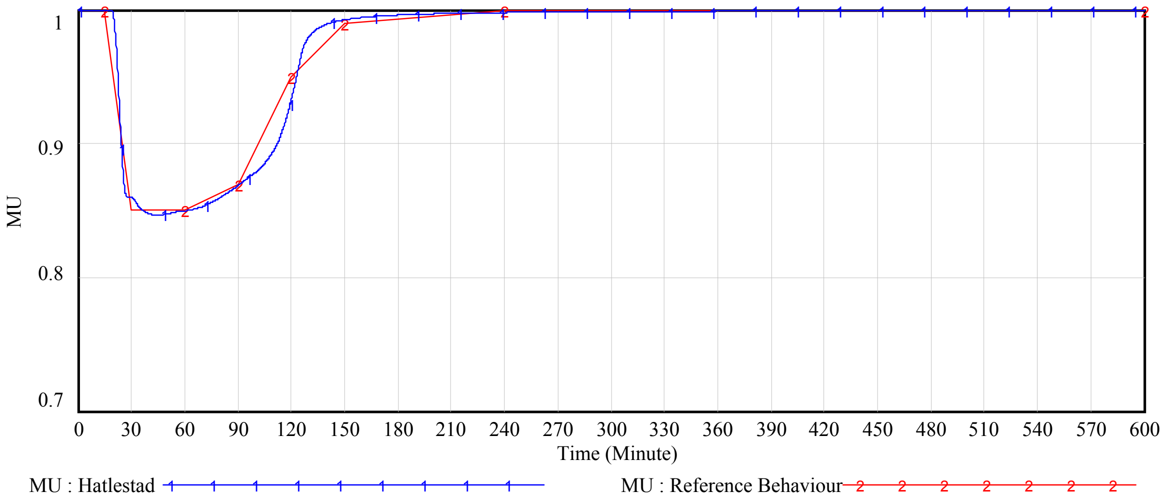

Figure 5 Comparison of simulated (1) vs reference (2) behaviour for *Mutual Understanding*

Invoking Lane (2008) one still needs a plausible account of why the model produces the behaviour that it does. A concise description of how the feedback loops depicted on Figure 2 drive the behaviour over time of *Cognitive Load, Local Innovation and Changes* and mutual understanding *MU* follows. For extensive details see Gonzalez et al. (2013) and the section "Exploring the underlying self-organisation dynamics" on p. 150 ff of Tu et al.'s work (2009).

Upon the arrival of the rescue teams to the disaster site the work rate increases sharply, which activates the balancing loop '*Performance Adjustment*' (Figure 2). The resulting increase in *Cognitive Load* forces *Cognitive Load Pressure* to increase. This results in corresponding sharp increases in *Local Innovation Changes*, *Error Generation rate* and *Errors*. The reinforcing '*Loop A'* acts as vicious loop and drives further increases of *Cognitive Load*, *Local Innovation and Changes* and *Errors*. The increase in *Local Innovation and Changes* decreases mutual understanding *MU*. The reinforcing '*Loop B'* becomes gradually dominant, resulting in further decrease in mutual understanding, increasing *Errors from Mismatch*, and driving *Local Innovations and Changes* further up. Since *Local Innovations and Changes* bring about improvements the dysfunctional situation starts reversing. As *Errors* decrease, mutual understanding increases, *Cognitive Load* decreases and with the reduction of the cognitive load, the need for improvisation (*Local Innovation and Changes*) declines. The reinforcing loop '*Self-referencing*' stimulates the growth in mutual understanding and a transition to a self-organised team working with higher mutual understanding and low cognitive load occurs.

MODEL ROBUSTNESS

The reference behaviour is highly qualitative, based on scattered fixed points of reference along the timeline and on speculative values on normalized scales [0, 1]. Lacking metrics for *Cognitive Load*, *Local Innovations and Changes* and mutual understanding *MU*, a conventional sensitivity analysis is less interesting than the question as to whether the simulation model is flexible enough to render different patterns of reference behaviour, constricted, however, by fixed points (such as the sudden drop in mutual understanding, extrema, etc) the observed transition from disorganisation to self-organisation. The short answer is that the model is quite robust – for details see Gonzalez et al. (2013). Hence, our confidence on the system dynamics model rests on its ability to render a class of reasonable reference behaviour shapes that could be derived from Lango's work (2010a, 2010b, 2011).

CONCLUSION AND DISCUSSION

The causal relations and the feedback loops shown on Figure 2 along with the robustness of the qualitative agreement of the simulated behaviour with the reference behaviour encourages us to suggest that the system dynamics model developed by Tu et al. as extended in this paper embodies a rudimentary middle-range theory for the transition from disorganisation to self-organisation in emergencies. We suggest that this rudimentary theory is worth exploring as a starting point to gain more, and much needed understanding of the management of disorganisation in emergencies.

Forrester (1980) argued that models in social science must use all three kinds of existing data, viz., data stored mentally in people's heads (mental data), data stored descriptively in writing (written data), and data available numerically (numerical data). The numerical data are a tiny fraction of what is found in written form, which again is tiny compared to what people have in their heads. Excluding essential mental data would be tantamount to trying to manage a business while ignoring perceptions, beliefs, sentiments, and all other key data upon which decisions must be made.

The huge of amount of mental data on emergency preparedness and response owned by practitioners is largely not available for scientists. Instead, the less abundant written data, and the even less abundant numerical data shape most of the current research on emergencies. By showing that even modest knowledge about the reference behaviour of soft variables can facilitate theory building, this paper aspires to motivate practitioners to share more of their mental data and to inspire researchers to include direct questions to the practitioners about data series, that is, reference behaviour for even the softest of the variables in forensic studies of emergencies. In particular, the power of Delphi techniques should be used to obtain such reference behaviour.

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