City evacuations: preparedness, warning, action and recovery

Final report of the DFUSE project (Game theory and adaptive networks for smart evacuations: EP/I005765/1)

March, 2013

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Introduction

This report, produced for policy makers and practitioners, gives the results of a two-year project funded by the EPSRC (Engineering and Physical Sciences Research Council) and the ESRC (Economic and Social Research Council) entitled 'Game Theory and Adaptive Networks for Smart Evacuations'. The project brought together expertise from both the physical and social sciences to bring interdisciplinary work to bear on the issue of city evacuations in the 21st Century. In particular, issues of social media and mobile communications have revolutionised emergency management and evacuation policy and this was foremost in our minds when conducting the project.

The research was informed by policy makers and practitioners from the outset. Representatives from three case study cities (London, Birmingham and Carlisle) were consulted at the start of the project about their needs in this area and two years later we returned to these groups to present our results. In addition, we interviewed and consulted experts from UK government, Department of Homeland Security and FEMA (Federal Emergency Management Agency). Aside from international academic conferences the results of the project were also presented to the Department of Homeland Security, the National Steering Committee for Warning and Informing the Public (NSCWIP), the Cabinet Office, the Home Office and local authorities (Essex, Plymouth and Exeter) as well as to experts from the sample cities. The project was also featured in national and international media (the BBC, Sunday Times, Reuters) and featured as part of the 2012 Cambridge Festival of Ideas.

The results of the project are presented in sections that examine:-

a. Differences in social media orientation between the cities (Lead: Warwick)
b. The dynamics of warning and informing the public in an emergency (Lead: Imperial)
c. Evaluation of evacuation strategies using social media (Lead: Sheffield)
d. Evacuation dynamics: a view from experimental physics (Lead: Manchester)
e. Social media and situational awareness (Lead: Lancaster)
f. Visualising social media in a crisis (Lead: Sheffield)
g. Deploying emergency personnel in crisis and evacuations (Lead: Manchester)
h. Using disaster education to prepare the public for evacuations (Lead: UEL)
i. Conclusions

a. A Critical Examination of the Potential Impact of Social Networking Technologies upon the Management of Emergency: A View from Organisation and Strategy

Introduction

It has been proposed that '*emergent uses of social media are pre-cursors of broader future changes to the institutional and organizational arrangements of disaster response'* (Sutton, Palen, and Shklovski, 2008). Social networking technologies arguably create virtual-spaces in which information can be shared with trusted agents, broadcast to the masses or traded through reciprocal, but largely informal and self-regulated, mechanisms. In a survey funded by The American Red Cross and conducted with a sample of 1,058 self-selecting US citizens it was found that one in six (16%) had '*used social media to get information about an emergency*'(2010). Within this sample younger respondents (18-34) were three times as likely to use social networking technologies to source emergency information (American Red Cross, 2010) arguably signalling that the use of social media is likely to be a growing trend in crisis communication. Social media platforms facilitate a new form and scale of citizen-organised information spread that may challenge centralised and government led modes of crisis communication. Harvard Business School Professor, Rosabeth Kanter recently wrote in her blog that '*global leaders are... running to catch up with the change triggered by Twitter, Facebook, and other social media*' (2010).

This analysis is based upon a literature review and qualitative data collected from five main streams: comparative city-level website analysis (approach semiotics), one national government and three city-level focus groups, one expert social media focus group, seven expert interviews and four data validation events. In three distinctive UK city locations research participants have been drawn from local authority emergency planning teams, blue light services, the media, social media experts, and citizen or business network groups. The sampled cities represent high and low density populations, reliable to unreliable telephone and internet coverage and varied local government levels of engagement with social media as a communication channel or social resource. The focus groups on the whole were well attended and the data collected was inter-organisational, rich and in-depth (the focus groups lasted between 1.5 and 4 hours). This research design produced a large comparative qualitative dataset which has been fully coded. The coding process surfaced strong themes within the data particularly in relation to points of similarity and difference between the three sampled cities. Key findings from the analysis included: the opportunities and threats of social media in the context of crisis communication and the potential for the construction of city level emergency communication archetypes.

The following sub-sections examine the extent to which the advent and uptake of new social networking technologies pose a challenge to traditional modes of government to citizen communication during crisis and subsequently suggests recommendations for practice and policy.

Re-thinking the link between communication and emergency management

The power of social media to compete with traditional media (e.g. television) during a period of crisis potentially has real consequences for how emergencies are managed. Arguably these technological platforms create geographically diffuse and self-organising groups of individuals who can source information for themselves in real time. For example, the micro-blogging application Twitter is both a network of linked individuals sharing information and a form of searchable broadcast media (i.e. tweets are published, publicly viewable and searchable). Kanter, argues that,

> *'America in the 20th century was called a "society of organizations". ... In the 21st century, America is rapidly becoming a society of networks, even within organizations. Maintenance of organizations as structures is less important than assembling resources to get results, even if the assemblage itself is loose and perishable'* (2009).

Social networking technologies present an opportunity for new and more immediate modes of organising citizen-to-citizen communication. The large quantity of textual data available through social networking technologies about the daily lives, observations and the movements of individuals offer a range of opportunities for the 'data-mining' and 'crowdsourcing' of information in a way that previously would not have been possible. For example one participant reported that,

> *"Social networks like Twitter are actually run in real-time ... the interesting statistic in the local area where I am, is that there's an average of five people on the network for every street. So they can be the eyes and ears. The community is on the ground, on the spot, 24/7, so they're going to be the first ones to start talking about any event"* (Community Participant).

There is subsequently potential for 'data-mining' of observer information:

- By the public(s)
- By business networks,
- By government organisations (local, national and international)

For example, consider the picture of the damage from 7/7 that was formed from citizen taken photographs. Traditional forms of media from print press to programmed news broadcasts have rapidly been supplemented, but not yet replaced, by social media modes of communication that are more frequent, accessible and interactive. Traditional media is also increasingly drawing upon citizen journalism, photography and reporting to gain first mover advantage on events as and when they occur. The people tweeting about events are often those right at its epicentre and therefore give access to first hand observations of an event in real-time. Social networking technologies therefore potentially bypass the need of the individual to engage with formal media as platforms like Twitter offer a searchable and ground-up basis for finding out, at least rumours, about what is occurring. If a number of individuals agree about the events in real time there is the potential for it to take on the status of reality:

> *"I think that the public trusts information it receives multiple times from multiple sources and if I was to put out a hundred different rumours to say that the new Mayor ... was actually blue and I was to put it over 30,000 different websites in all different ways and then a trusted authoritative person was to stand on the Council steps and say "No, the Mayor is not blue, I guarantee" everyone is going to think the Mayor is blue..."* (Business Network Leader).

As trust in government and also media channels has arguably been reduced the role of such emergent and grassroots based information may become increasingly persuasive and pervasive. This may create challenges for effective evacuation as the flow of information can no longer be controlled.

The data analysis supports that social media platforms present a disruptive technological challenge to the assumption of publics as passive recipients and consumers of one directional emergency broadcasts through traditional media channels (e.g. radio and television). The new context created by social media can be characterised as an information market place where individuals can source information (specific and aggregated) for themselves, in real time (e.g. by using Twitter as both a network and as a broadcast media). The information marketplace may mean that official information is no longer automatically prioritised or believed by the public, as the voice of government becomes one among many:

> "*You have to establish yourself as a voice of authority because there's a lot of noises, there are so many different sources now with any story and if you don't establish your authority, then when you do have something important to tell communities, they're not coming to you, so it doesn't matter"* (Police Communications Team Member).

The next sub-sections explore the opportunities and challenges that this change creates for the government management of crisis communication.

Potential implications of social media for emergency management

Data analysis revealed participants perceptions about the key implications of social media for emergency planning. These themes are summarised in table 1 and broadly reflect the trends found in the narrow ranges of publications and comments that currently exist on the topic.

Table 1: summary of the opportunities and threats of social media for emergency planning

Opportunities of social networking technologies
• Real time • Ability to ask questions to many • Trusted by public • High levels of use • Potential for data mining of observer information a. by public, b. By business networks, c. by Government organisations • Opportunity for harnessing social media knowledge and therefore the public as a form of social sensor and resource
Threats of social networking technologies
• False rumour (competing with official information) • Information getting out too early (public observers / leaks) • Networks / platforms not robust • Public don't trust them • Public don't use them • Discriminatory demographic effects in relation to the profile of users • Skill, resource and willingness of emergency managers to respond to both challenges and opportunities of social media

In particular it is worth noting that a dichotomy emerged between those respondents who rejected social media as a significant macro-environmental change and those who saw social media as potentially impactful. Respondents who considered social media as potentially high impact could be further sub-divided between those who framed it as primarily a threat and those who saw the potential to harness information and /or to communicate through social media platforms.

The self-sourcing of information may also present challenges for government control and coordination and for equality of access (e.g. technology inequalities). In this process the citizen engaged in social media is recast from passive recipient to potential searcher, creator or collator of communication. It has been argued that '*...local communities might become more responsible for their risk management*' (Coaffee and Rogers, 2008) and this is clear in the current UK public policy emphasis on promoting individual and organisational resilience. However, In the case of evacuation this competes with the enduring message of '*go in, stay in, tune in*':

> *'In a major emergency, if you are not involved in the incident, but are close by or believe you may be in danger, the best advice is to go inside a safe building, stay inside until you are advised to do otherwise, and tune in to local radio or TV for information'* (NSCWIP, 2010).

There are subsequently a number of key policy and practice issues in relation to the use of social networking technologies in emergency management whether it is by citizens, market or state organisations (or a combination).

Firstly, loose networks may lead to increased risk. In section 1.21 of the UK National Security Strategy (2010) the potential impact of a new 'mass of connections' upon security was highlighted. It was argued that networks, including social networking technologies and 24 hour news media, could impact security as interest groups become more able to pressurise governments and a wide range of ideas easily proliferate globally (UK National Security Strategy, 2010). A recent article on ZDNet covered nation 'unfriend day' which argued that loose connections on Facebook lead to increased risk of terrorism (2010).

Secondly, groups of social media users could lead to the propagation of both intentional and unintentional rumours on internet platforms. These information flows may have significant implications as government policy and official communication is ignored with potentially serious consequences. In January 2010 a Twitter rumour led to the evacuation of Grand Central Station in Manhattan. One journalist was watching the rumour unfold in real time and commented that '*streaming before my eyes was both the ebb and flow of traffic itself but the ebb and flow of rumour* (Bnet, 2010). Multiple versions of the rumour quickly spread through Twitter with information ranging from:

- That subway trains were bypassing Grand Central;
- That there were SWAT teams on the subway platforms;
- That there had been a dirty bomb;
- That there had been a steam explosion, resulting in one death and 15 injured;
- That the entire report was a Twitter hoax,

(Source, Bnet, 2010).

Interestingly a number of posts also suggested sourcing trustworthy information from Twitter as opposed to traditional media.

Finally, at The Red Cross hosted Emergency Social Data Summit a key conclusion was that '*the major obstacle to the use of social media in crisis situation is the same obstacle to adoption we've seen since the beginning of the technology: a hesitation to shift from broadcasting information to engaging information*'(American Red Cross survey, 2010). Getting emergency managers in particular to embrace and adapt to these new technologies in an age of not only uncertainty but resource scarcity may be a key challenge. It is not clear that the skills and resources currently exist within local emergency management teams to confront the social media challenge.

The next sub-section examines the capabilities required by local authority emergency management teams to capitalise upon the threats and opportunities of social media in relation to crisis communication. Further an initial version of a tool by which to evaluate the appropriate crisis communication strategy for a city is proposed.

City level Archetypes

The data analysis strongly indicated that one size of policy does not fit all city locations when considering government crisis communication. This theme emerges from an evaluation of the differences and similarities between city locations. Through the data analysis process 12 key factors (as reported by participants) were identified. Whilst these are aggregated at city level, theoretically this analysis broadly draws upon the resource based view of organizing which looks at ways in which resources and capabilities can be leveraged to achieve a strategic goal (i.e. in this case smarter crisis communication). Through a thematic coding process the general trend for the orientation and/or the substantive actions (i.e. plans, processes and websites) within each city context were identified. The next step was, where possible, to evaluate these factors in relation to existing resources and capabilities within the three city contexts (i.e., on the basis of participant reporting and the website analysis).

Of particular importance in the resource based view is the role of core and dynamic capabilities. These are bundles of resources and capabilities which either best use the unique advantages of an organization (core) (Wenerfelt, 1995) or enable an organisation to achieve high levels of flexibility in their strategic responses (dynamic) (Teece, Pisano & Shuen, 1997). The archetypes in effect represent a judgement about the core capabilities within each city context. It is proposed that by evaluating UK cities against these 12 factors and determining their closest archetype that (if validated) this will both indicate likely core capabilities and highlight potential areas of weakness, thus offering an effective foundation for building capacity in a way which recognises city level differences.

There are a range of limitations with using the resource based view which ought to be recognised such as its primary focus upon the private sector and the organisational unit of analysis. However, this set of ideas is increasingly highlighted as a key frame for considering resilience capacity building in both the private and public sector (e.g. a range of international papers made this link at the European Group for Organisational Studies Colloquium sub-theme 15 'Transboundary Risks and Crisis Management' in 2011).

Indication of the data

In order to explicate the process behind the creation of the archetypes two factors will be unpacked and illustrated by indicative quotations: information sourcing and orientation to social networking technologies.

Factor 1: information sourcing

Practices in relation to information sourcing were assessed through direct questions in all focus groups. Whilst there were a number of common themes (e.g. word of mouth) in all locations there was also substantial variation in the central tendency by city. This can be seen in the following representative participant quotations which relate to real life examples:

City 1: "*we got a phone call from them to say there's a big fire ... looks like a school, do you need anything, do you know about it?' We didn't know about it so I went on to Twitter, searched the area, and then all these posts come up about, you know, primary school's on fire, big smoke etc. So that in effect validated what we'd heard, allowed us to then say actually we've got to do something now"*

Interpretation: whilst word of mouth was still prevalent the vast majority of participants and one expert interviewee identified an internet search (or specifically Twitter) as a key information source (either initial, validation or for further information). Multiple sources were seen as critical and basic systems such as Google trends were being used by a number of participants as a means of picking up weak signals about events, although they did not have access to sophisticated data mining tools.

City 2: *'phone call from a friend or colleague who is there or local radio'*

Interpretation: information tended to be sourced face-to-face at an individual level, i.e. street level intelligence from citizens, police or fire officers. The local radio was also seen as a critical and dependable mode of communication. Very little attention was paid by participants to the internet; in particular this was equated to high failure rates for mobile communication signals in the area.

City 3: "*Well, apart from person to person spreading the message that way, and I guess these days people texting each other, maybe tweeting or whatever. But I can imagine it being informal... People starting to, have you heard about this, going on. But I'd agree with colleagues, I mean, the way we might get the information at my control centre would be through the TV we've got on, through Sky News telling us something might be going on, you know, even at that level*".

City 3: "*I think we would be thinking that there isn't one definitive feed'*

Interpretation: participants in general focussed on publicly available sources of information such as individuals or TV (not necessarily BBC who were seen to be slower due to their validation process) however it was also indicated that multiple sources of information would be scanned across routinely. It was unclear how effective this process was on picking up weak signals or the degree to which this used technologically driven solutions such as data mining.

Factor 2: orientation to social networking technologies

Orientation to social networking technologies was assessed through direct questions in all focus groups. There was, as anticipated, substantial variation in the central tendency by city. This can be seen in the following representative participant quotations which relate to real life examples:

City 1: "*there was example a couple of weeks ago, there was a suspected gunman in the Tesco's. Now, my partner works [there] so when I saw it on Twitter, I emailed him straightaway and said there's an incident outside your work and there's a potential gunman there. And he said "Oh, I wondered what it was because all the traffic had stopped" so he could actually see the incident but I knew more about it than he did because I was on Twitter and he wasn't. ... The point I wanted to make about resilience was that I got the text 45 minutes after Twitter".*

Interpretation: High social media as a means of sourcing and communicating information, rapidity of dissemination and competing information sources seen as critical drivers.

City 2: *'there isn't a high level of use here because of the type of community that we are and the technologies couldn't be relied upon anyway as we don't get good phone coverage'*

Interpretation: Low orientation and therefore low capability as a result of both perceived value and the dependability of Smartphone signals.

City 3: *"there would be a formal structure, a formal way of communicating that works, the public need to know"... "I mean, for example, if I was sitting at home say and there was an event out there, I'd have the TV, the main news sites*"

Interpretation: Mixed orientation to social media as it appeared to be acknowledged and understood but on the periphery of discussion as official channels, TV and to a lesser extent internet were seen to be the primary ports of call for information.

By looking at two of the 12 identified factors in-depth the above sets of quotations and interpretations indicates how the relationship between a factor and city level resources and capabilities has been assessed. The final section summarises the factors in full, the data sources which form the basis for each of the 36 evaluations and subsequently the city-level archetypes. A full breakdown of the analysis can be made available on request.

Summary: city crisis communication archetypes

The 12 identified factors and the associated initial resource and capability audit is sumarised in table 2 below. The evaluative cells (i.e. city 1 approach to initial information gathering) also give an indication of the evidence source for each judgment.

Table 2: Summary of city level crisis management and communication archetypes

Key
FG = focus group
EI = expert interview
WA = website analysis

Factors	City 1	City 2	City 3
Initial information source	Scanning of multiple sources (FG/ EI)	Individuals / radio (FG)	Individuals/ scanning (FG)
Orientation to social media	High (FG)	Low (FG)	Low (FG/ WA)
Assumption of information spread	Mixed media (FG)	In person; phone (FG)	Official channels (FG)
Use of social media	High (FG/ WA)	Low (FG/ WA)	Low (FG/ WA)
Perceived risk of social media	High (recognised threat to information control + rumour) (FG)	Low (assumed low use / robustness) (FG)	Mixed (FG)
Intervention strategy	Official (but competing) information (FG/ EI)	Belief in face-to-face (FG)	Multiple official (e.g. BBC, e-displays) (FG)
Structural complexity	Low (unitary authority) (WA)	Low (but geographic spread) (WA)	High (WA)
Planning orientation	Specific (FG)	Adaptive (FG)	Generic /adaptive (FG)
Information control strategy	Information control (high)	Street level intervention (medium)	Data unclear
Public accessibility of information (web)	High (WA)	Low (WA)	Mixed (WA)
Use of social Capital	Low (FG)	High (FG)	Mixed (FG/ WA)
Organisational style	Inward (FG)	Outward (FG)	Central Government (FG)
City archetypes	***Digital director***	***Grassroots gatherer***	***Central communicator***

Whilst these evaluative judgements and the range of factors considered require further validation and testing in a wider range of UK cities the analysis of the initial dataset does indicate:

a) That these factors are perecieved by experts and practitioners to be important.
b) The capabilities associated with these factors substantially vary by city (although the nuance is as yet not determined).
c) That the core capability of each city is different.
d) That nationally driven capacity building may optimally require a recognition of a range of city archetypes (e.g. investment in social capital/ resource in grassroot gatheree cities rather than in social media upskilling).

This initial analysis highlights a number of research gaps in the area of crisis communication and social media, particularly in the areas of capability building and social media influence.

Key implications for policy and practice

Social media platforms present a disruptive technological challenge to the assumption of publics as passive recipients and consumers of one-directional emergency broadcasts through traditional media channels (e.g. radio and television). The new context produced by social media can be characterised as an information market place where individuals can source information (specific and aggregated) for themselves, in real time (e.g. by using Twitter as both a network and as a broadcast media). Data-mining information from, in particular, micro-blogs is a potentially innovative way of harnessing social resource either through:

- Data-mining of first hand observations that people have posted to the internet unprompted,
- Requesting textual or visual information from members of the public within a particular geographic area (e.g. via cell broadcast or emergency warning sign-up programs),
- Weak signal detection through automated textual and visual process of social media posts.

The self-sourcing of information may present challenges for control and coordination and opportunities for sourcing citizen information and resource. This research therefore indicates that whilst social media requires new emergency management monitoring and intervention strategies but one strategy is unlikely to fit all locations as a range of factors need to be taken into considered.

b. Warning and informing the public in a crisis

Two models of information spread (King, J. & Jones, N., 2014, Forthcoming).

Our part of the project investigated how information about a crisis might spread through a population of individuals (King & Jones, 2014, Forthcoming). Specifically, we are interested in how long it takes for information to spread and the manner in which people learn about the crisis. We used two very simple mathematical models to investigate this setting: a "mixed population model" and a "microscopic model". We aimed to use the simplest possible models so that we could contextualize their insights and understand their failings. We suppose that individuals learn about the crisis through three routes: 1) consuming media at the time the crisis is broadcast 2) through spontaneously switching on broadcast media as part of their normal daily activities 3) through socially driven sharing mechanisms e.g. personal phone calls or facebook.

Assumptions (non-exhaustive): We suppose that the crisis that occurs is of relevance to all citizens. We consider that each individual, shortly after being informed has a trusted source which allows this information to be quickly verified. We suppose that all mass media sources are immediately saturated with this information: turning on a TV/Radio/news website effectively informs the individual.

Mixed population model: We used hourly media consumption statistics (from RAJAR, BARB and news website use) and, importantly, the rate at which citizens activated that media type (logins/switch-ons). Between approximately 7am-10pm 30-40% of citizens (assuming that simultaneous consumption of different media types does not occur) are consuming either radio or television. Consumption falls markedly outside this window (down to a few percent at ~3am). The dynamics of this model are then specified by the spontaneous switch-on rates of individuals (something which varies with time through our model) and social feedback which we suppose is proportionate to the fraction of informed individuals. There is no obvious way to scale the effect of social feedback; but we find that, over a range of social-feedback strengths, the time to reach the majority of people is dominated by time-of-day effects: events during the high-broadcast consumption window spread rapidly whereas events outside it are very sensitive to the choice of the strength of social feedback (the duration of the low-broadcast window is an important timescale). A desire to accommodate the fact that social spreading is a networked phenomenon and to attempt to give it a more realistic treatment motivated our next model.

Microscopic model: In this (agent-based) model we computationally simulate the spreading of information across a social network. Alongside a spontaneous rate at which individuals become informed (when they log-in/turn-on informative media) they can also acquire information if they have a social link to an informed individual. We make a distinction between methods of social communication which are direct (e.g. telephone calls) and indirect (e.g. facebook postings). In the former the communicator gives information to their target without an intermediate step. In the latter the communicator informs all of their friends but each friend has to log-in in order to receive this information. In the direct case, limiting factors are the number and frequency of direct contacts made; in the indirect case, a limiting factor is the log-in rate of friends.

Shortcomings: Before discussing model-specific implications it is worthwhile highlighting a selection of shortcomings of our models. Though our microscopic model is more realistic than our mixed model it is by no means realistic: agent-based models gain apparent realism at the cost of introducing parameters and more particular assumptions. We supposed that all types of social contact occur on the same social network; this is not true: different forms of social tool can have very different network structures. Arguably there are intermediates between direct and indirect communications: e.g. phone pushes, sms alerts, "you've got mail " alerts. These occupy a spectrum of degrees of attention by the message receiver which is likely to be increasingly populated. We consider a simple rule in which individuals make a finite number of direct communications (all of which are assumed successful) at a fixed rate: in reality, all of these quantities will be variable (between individuals and over time) and neighbours in the network will have correlated properties (i.e. there might be subparts of the social network which communicate faster and more frequently than others). This, in turn, is related to

demographic effects which we also neglect. We have not studied weekend effects and we could reasonably expect different dynamics on weekends.

Model-specific implications: We find that during the high broadcast media use window, 7am-10pm, a majority of the model population is rapidly informed in a manner and timescale which is partly robust to details of model choice. A critical "realize-and-relate" timescale is the interval between the alert appearing (for the first time) on an already switched-on TV/Radio and a direct communication by the media consumer to another person. The individual thus has to realize that there is a problem by attending to the media he/she has switched on and to decide to communicate it. Because of the high-rate of media consumption over this window one might expect a substantial burst of communication after this critical timescale: 30-40% of the recently informed population will be making communications. This will likely yield a public which is majority informed on a timescale comparable to the realize-and-relate duration and has implications for the traffic capacity of our communication networks. Direct communication, initialized by a large number of consumers of broadcast media were the dominant day-time effects (independent of model choice regarding details of cascades of communication and multiple direct communication by the same user). We note that, if these model-specific insights are assumed to be relevant, whether the broadcast media is encouraging consumers to call others (or discouraging them), and who it recommends should be contacted, could have a large effect on the rate of spreading across the population (and the distribution of realize-and-relate timescales across individuals).

In our model we supposed that individuals only communicated information to a finite number of randomly selected acquaintances. This yielded isolated islands of uninformed individuals surrounded by informed neighbours that had ceased informing others. For these individuals, their rate of switching on media was important. Though our information about log-in rates for social media was patchy, the evidence we had suggested that switch-on rates totalled a few percent of the population per hour for new or web-based media as opposed to ~20% for the combination of TV and Radio. So again, the rate at which people were spontaneously informed was dominated by old-media.

During the window 10pm-7am the details of model choice were particularly important. Rates of consumption and rates of media log-ins are much lower and so cascades of direct contacts are particularly important. As such, estimates of the timescales at which the majority of the population is informed are more sensitive to details of model choice and the parameters used. There is an interplay between two characteristic timescales: (i) the time between the crisis start and ~7am (when the nation tunes-in) and (ii) the interval between successive phone calls (modulated by population size and number of calls per individual). Bursty calling behaviour and details of the phone-call network structure are likely to have important effects on estimates of this rate and we did not consider these in our models.

The relatively minor role played by new media in our models might seem surprising. We note the strong assumption that new media is indirect and requires a log-in to be consumed. Because this log-in rate is low this becomes a limiting factor. This is in contrast to direct communications which are received immediately within our model. It is important to make a distinction between the role that twitter, facebook etc have in an on-going crisis and their role as a source of first information. While new media may be important when the consumers are already informed (e.g. in the London Riots) in our simulated crisis, their relatively low log-in rates (and low numbers logged in at any one time) compared to radio/TV have a substantial effect on their role.

This three-way split between Radio/TV as rapidly seeding a large part of the population, direct social contact as generating a rapid second wave (with concomitant strain on communication networks), and a minor role for social media is likely to change. As fewer people consume information in a synchronized fashion through TV/radio we might expect that a smaller fraction of the population will be immediately informed. Since this is the dominant effect we observe in our model, this would have a marked effect on how our simulated crisis would unfold. As we shift to different social media the particular network structure of these types (and the peculiarities of their usage) will become increasingly important in order to characterize the time to reach the population.

Other and further work: (King & Jones, 2011; King, Johnston & Jones, In Preparation)

Our model development was supported by insights from the expert interviews collected by other members of the team. Further information at a more microscopic level, explaining how social information spreading changes during a crisis, should be included to strengthen the model. Having an understanding of the individual-to-individual variability in the realize-and-relate timescale would likely be very helpful. An empirical study showing how this timescale (and its variability) could be controlled by using different types of announcement would obviously be relevant.

While we awaited the results of the expert interviews we also considered a computational framework in which optimal information distribution could be investigated (King & Jones, 2011). Our motivating question was which individuals within the network should be targeted first in order to accelerate the deterministic spread of information. This is one of a generic set of combinatorial landscape problems and we will make code for probing such problems available online (King, Johnston & Jones, In preparation)

We have also made a brief investigation of the interaction of rumour and counter rumour on social networks. In this we supposed that every time a person was informed, conditional on the number of their friends who believed the information, they would either believe the information or actively combat its spread. In the models described above we assumed that there was no notion of doubt and that everyone would be able to verify quickly a rumour via a trusted source. If there is no such source then past experiences and the opinions of social contacts become particularly important. An area we intend to develop is how prior beliefs evolve as individuals swap information on social networks: noting a duality between coupled urn models and models of Bayesian inference by a population, this becomes both a mathematically rich and relevant topic for further investigation.

c. Evaluation of evacuation strategies based on Social Media

a) The effectiveness of evacuation strategies

In this section we evaluate the effectiveness of evacuation strategies using information from Social Media. Using insights from statistical physics (Galla, 2011) the basic idea is to evacuate n_i individuals to Route i so that global evacuation is conducted as quickly as possible. Each route is defined by two physical parameters: thickness K_i, journey time to a place of safety J_i (Figure 1).

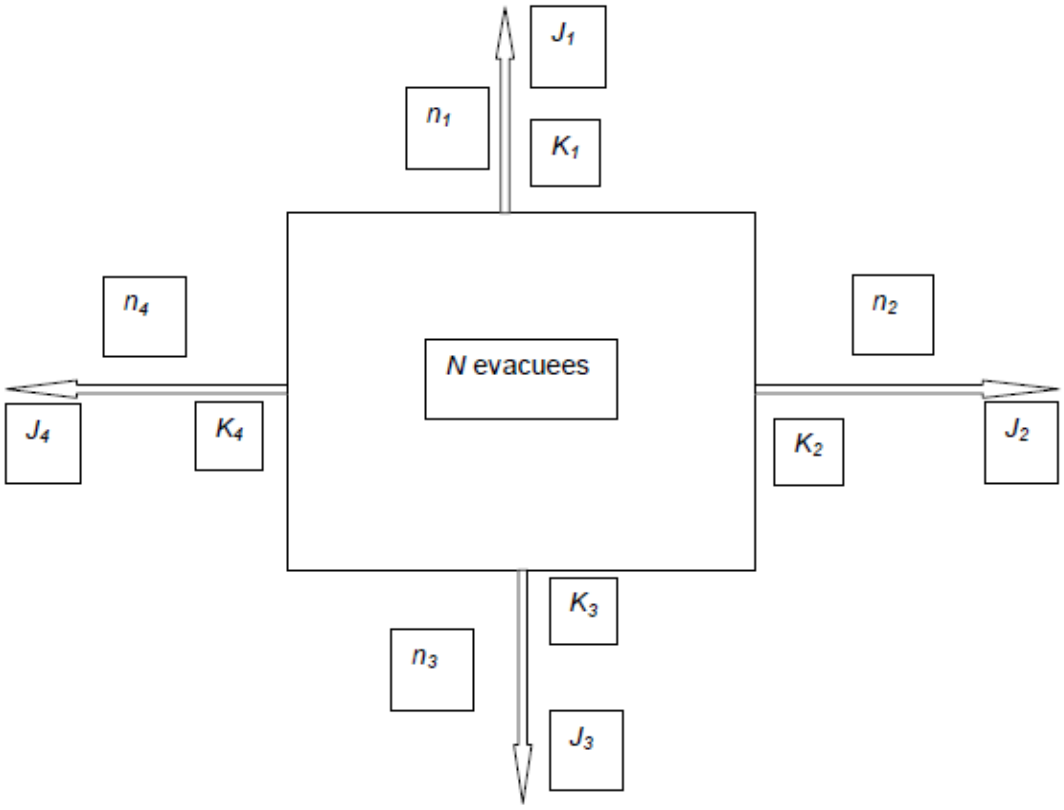


Figure 1: Schematic of the model

The model is exactly soluble and linked to classical dynamical flow models in OR (Chalmet et al. 1982; Jarvis and Ratliff, 1982). The optimal solution is

$$\frac{n_i}{K_i} + J_i = Const. \tag{1}$$

Equation (1) simultaneously satisfies multiple optimisation criteria so its optimality is robust. Extensions of this basic model include sequentially arriving information and safest (as opposed to fastest) escape problems (Opsasanon and Miller-Hooks, 2009).

The key issue that emerged from discussions with policymakers was the distinction between high-quality and low-quality information. Under a high-quality regime information obtained from Social Media is trustworthy and can be used to co-ordinate faster evacuations. Analytical and computer simulation results confirm that as the size of delays, detected by Social Media, increases the

potential benefits of Social Media increases. Not using information from Social Media may increase final evacuation times by as much as 350% (see Figure 2).

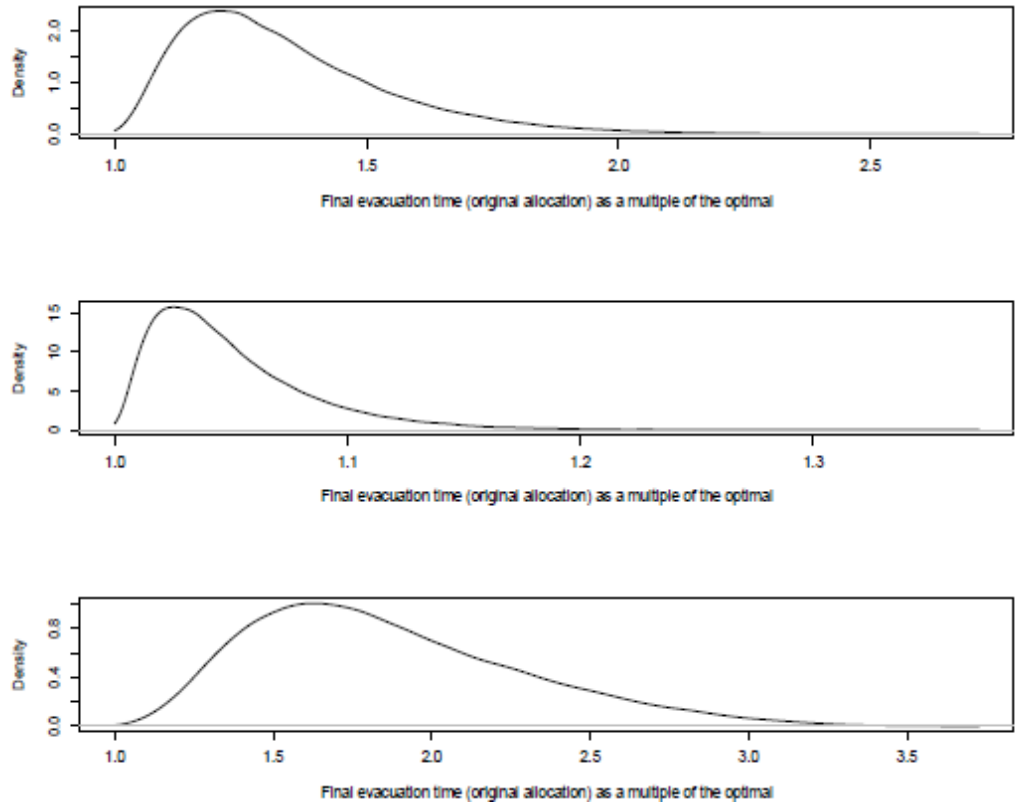


Figure 2: Final evacuation times ignoring information from Social Media as a multiple of the optimal allocation using information Social Media. Top Panel: Delays independent of critical infrastructure. Middle Panel: Delays absorbed by critical infrastructure (ideal scenario). Bottom Panel: Delays exacerbated by critical infrastructure (most realistic scenario?).

If information from Social Media is less accurate strategies based on the random allocation of individuals to exits may be more effective[1] (see Figure 3). Only when Social Media provides accurate information (low σ) and is well-used (high p) is a random strategy bettered. Analytical results for the high-quality/low-quality information threshold exist and may be used to assist policymakers. Additional simulation results are shown in Figure 4. For low values of σ (high-quality information) Social-Media-based strategies perform best. However, for $\sigma > 2.5$ the random strategy performs best.

[1] In certain terrorism cases random evacuation strategies may be preferable for other reasons. In Mumbai terrorists exploited information from Social Media to target certain individuals (Oh et al., 2011). Using information from Social Media in a predictable way may enable terrorists to co-ordinate secondary attacks.

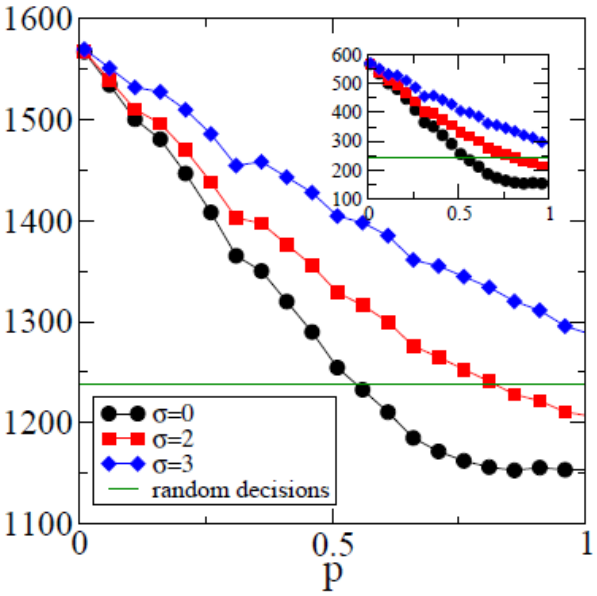


Figure 3: Simulation results: Total evacuation time for Social-Media-based and random strategies as a function of the faction, p, of agents with access to information.

σ	Mean	Standard Dev.
0.5	722.908	106.383
1.0	768.148	183.077
1.5	793.984	270.214
2.0	809.014	363.534
2.5	820.322	483.132
3.0	827.584	648.768
3.5	832.551	791.694
4.0	837.216	1030.141
4.5	838.938	1336.267
5.0	841.727	1891.248
Random Strategy	821.115	130.082

Figure 4: Simulation results: Social-Media-based and random strategies

The implications of this model are that the quality of social media information is particularly important when considering evacuation times. However, whilst this result might hold true for a stylised model of evacuation where there is a simple decision process as the next section shows in some situations peer to peer communication may impede the progress of an evacuation.

d. Evacuation dynamics: a physics view

(NB: Based on Smyrnakis & Galla, 2012)

1. Optimizing evacuation flow in simple exclusion processes

We have studied a simple evacuation model (Galla, 2011; 2012), in which particles (pedestrians) are propagated in space by a basic exclusion rule, space is discretized into individual cells, and particles move in their desired direction whenever the cell ahead is vacant. They are unable to move when the cell ahead is occupied by another agent. Such models were first proposed in the context of biological transport, but are also widely used to model traffic or pedestrians.

In our simple model agents have the choice between two exit routes. We use methods from statistical physics to derive an analytical mathematical solution to this model, allowing an external controller to optimize the flux through the system by directing agents into one of the two exit routes. We focus on both static intervention techniques and dynamical approaches, in which the system manager directs incoming evacuees into one of the two branches depending on the current densities of agents in each exit route. Computer simulations show that this can further enhance the flow through the system.

In a second project related to exclusion processes we have adapted a technique known as the system-size expansion to the case of meta-population exclusion models. These methods allow one to analytically predict the magnitude of fluctuations in simple agent-based models of transport, for example fluctuations of the total number of particles in the system or their spatio-temporal correlation. Ongoing work in this direction will address more intricate models such as for example the celebrated Nagel-Schreckenberg cellular automaton model of traffic jam formation.

2. Effects of communication and utility-based decision making in simple models of evacuation

Using a simple cellular automaton model we studied the effects of communication and decision making in an agent-based model of evacuation. We considered a scenario in which evacuees are placed in a central region, which is being evacuated. They have the choice between two exit routes, one of which is intrinsically faster than the other (e.g. a wide corridor versus a more narrow one). Agents can dynamically decide between these escape routes. Initially agents simply head towards the geometrically nearest exit, but they can revise their decisions based on information they receive or deduce from their surroundings during the evacuation. For example they may find that they progress slowly towards their destination, when the opposite escape route provides a seemingly smoother evacuation flow. They may also receive information from other agents, by means of peer-to-peer communication (e.g. mobile phones). This generates a game theoretic scenario, in that all agents have the same objective function (evacuate as quickly as possible), but acting according to it may slow down the process (if all agents choose the wider exit, this escape route will quickly become jammed). Our analysis is carried out using computer simulations. We focus in particular on the efficiency of evacuation as a function of the fraction of agents who have access to communication. Results indicate that under certain circumstances there is an optimal fraction of communicating agents in this model guaranteeing fastest evacuation, see data. If fewer than this optimal fraction of agents communicate, evacuees make sub-optimal choices due to lack of information. If the number of communicating agents exceeds the optimal ratio then agents are `over-informed' and frequently change their minds during the process, slowing down the overall efficiency.

3. Large-scale agent-based model of Manchester

(This section based on: R. Dawson, P. Hamnett, T. Galla, In preparation)

Galla is currently supervising two MPhys students at Manchester working on the simulation of vehicular traffic, continued as a summer project in July and August 2012. The students have implemented the well-known Nagel-Schreckenberg model (a cellular automaton), and have applied it

to simple configurations such as Manhattan grids, investigating the efficiency of evacuation as a function of parameters of the decision making and route-finding algorithms applied by evacuees. The students have also used Open Street Map (**www.openstreetmap.org**) to download and parse real-world data describing the geographics of Manchester. Converting this data into a suitable format they have created a cellular-automaton based simulation of the road network of Manchester, see figure 9. Work in progress addresses the properties of this scenario as a function of decision-making rules, path-finding algorithms and communication between agents.

As one part of our simulation studies we have considered a staged evacuation process, in which agents in a central area in Manchester are informed about a disaster and told to evacuate, but where individuals outside this area are not told initially by authorities. The simulation includes communication though, so that individuals outside the initial evacuation zone learn about the evacuation and start moving themselves. This slows down evacuation of the central area due to jamming. Even a small fraction of communicating agents can slow down the evacuation process significantly.

4. Dynamic intervention in a two-channel meta-population exclusion process using data from the Westfield Opening Observation Exercise data (work with Kolokitha and Preston, UEL)

(This section based on Smyrnakis, Kolokitha, Galla, & Preston (working paper)

We have also analysed the data of Westfield Opening Observation Exercise (WOOE) that took place in Stratford train station. Pedestrians that use Stratford train station face a decision-making problem similar to the one that is depicted in the figure on the left. They should choose one of the two available corridors in order to reach their platform. These corridors are of different size and from our analysis we observed that for large time intervals the majority of the pedestrians use the narrow corridor. This inspired us to study the impact of intervention policies, both static and dynamic, in the average time pedestrians need to reach their destination. We used an abstract representation of this scenario, where pedestrians are placed in a central urn and they have to choose one of the two available corridors (one narrow, the other wide) and we used the meta-population exclusion process to model pedestrians' motion.

In order to make our simulations more realistic we used the data from the WOOE to define the parameters of our model. In particular we used the WOOE data to define the rates that people arrived in the central urn and choose one of the two corridors. We also used the extracted data as a tuning mechanism in order to validate the output of our simulations. We observe the average time that pedestrians needed to exit the configuration was reduced in our model by more than 20% when a dynamic intervention policy was used.

e. Social media and situation awareness

The focus groups and proposed city level archetypes demonstrate very different levels of perceived importance of social media when planning for emergencies. This must be viewed in context. Whilst it is more than likely that the prominent social media applications will vary with time yesterday's Instant Messenger and MySpace are today's Twitter and Facebook (Young, 2012), it is almost certain that social media itself with grow in prevalence and importance in society.

In practice, this means that even if viewed as of only moderate importance in emergency planning at the present time, it is necessary to understand how messages are conveyed via an application such as Twitter so that accurate interpretations can be made and appropriate strategies for intervention developed. Twitter messages have a character that changes over time with respect to the subject being discussed. In the next section, we will consider a small case study that involves a plane crash at Cork airport.

Cork Crash Case Study

In February 2011 (10/2/11), Flight Avia No FLT400C from Belfast to Cork crashed at Cork Airport at 10.15. There were 12 people on board and the crash resulted in six casualties and six survivors. Cork Airport Major Emergency Plan activated at 10.18am, and stood down at 11.04am. Over a 72 hour period, a data set of geo-coded Twitter messages was collected covering the UK and Ireland (numbering approximately 340,000 tweets). This data set was searched for massages relevant to the crash using key words and manual intervention, resulting in a modified data set of 243 records. Figure 5 shows the distribution of the records identified.

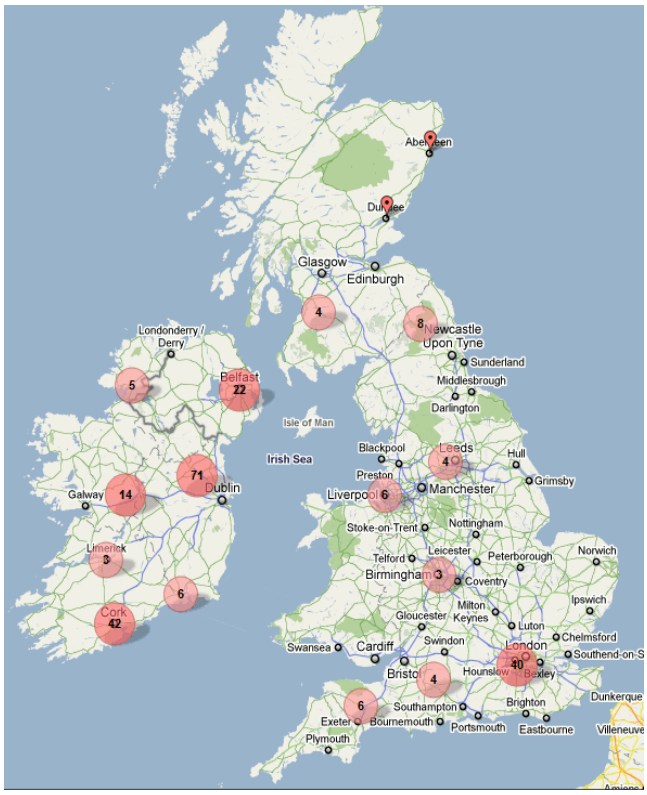


Figure 5: Distribution of Cork crash records

In order to understand the temporal quality of the messages sent on Twitter, records were annotated according to Situation Awareness (SA) categories (Endsley, 1995):

- **Perception**
  - Information seeking
  - Information sharing
- **Comprehension**
  - Emotional engagement
- **Projection**
  - Opinion sharing

In SA Phase 1, members of the public seek and share information about the event that has occurred – this is *perception*. As people gain a better understanding of the event that has occurred, SA Phase 2 – *comprehension* – messages are used to show an emotions engagement with what has happened. In SA Phase 3, members of the public begin to share insights, opinions and suggestions – *projection*.

Examples of messages assigned to these categories are given below:

- **SA Phase 1: Perception**
  - Information Seeking *"What's happening in #cork airport?"*
  - Information Sharing "*Plane crashes in Cork Airport"* (includes post with links)
- **SA Phase 2: Comprehension**
  - Emotional Engagement *"Very sad news in Cork. Thoughts with the families of the victims."*
- **SA Phase 3: Projection**
  - Reflection/Opinion Sharing *"Re #corkaircrash ... They'll be checking the flight and weather tapes. Who still uses tape for backup storage?"*

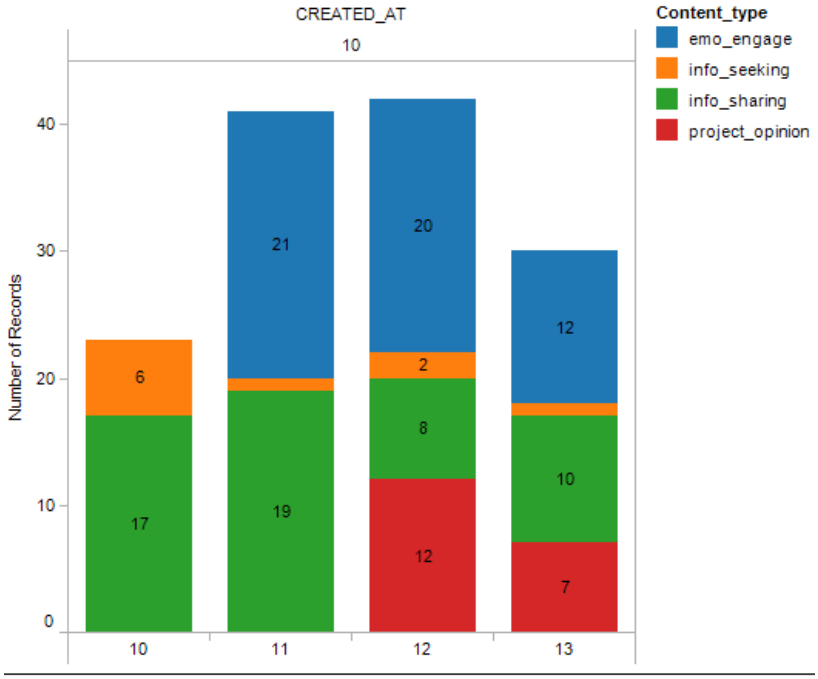


Figure 6: Content type (within the first four hours of the crash 10.00-14.00)

Figure 6 shows how the content of Twitter messages varies with time – in this case, the first 4 hours following the Cork airport crash. Figure 7 offers a different view of message distribution, over a longer period.

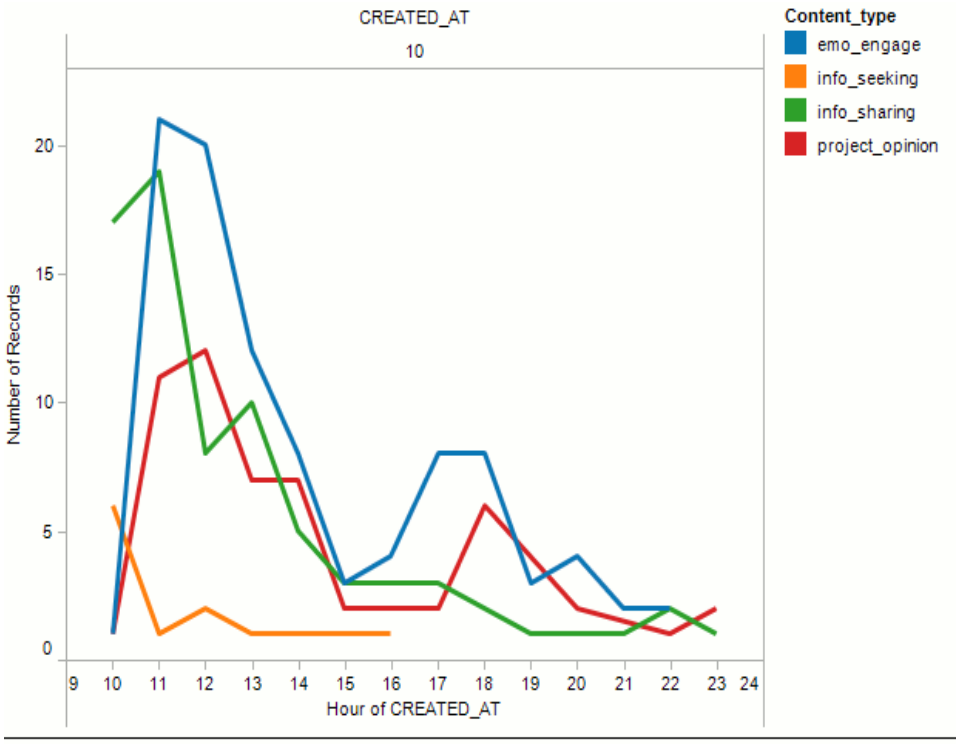


Figure 7: Content Types Over Time (10/02/2011 only)

The different types of content display different characteristics. When we consider information sharing and seeking, we can see that descriptions of the accident vary with time and can display a sort of "self correction". The following examples illustrate this:

"RTE just mentioned unconfirmed reports of 8 dead at Cork Airport [...]" (10.41am)

"Now - 3 confirmed dead @ Cork Airport #cork" (11.13am)

"6 Now confirmed dead in Cork plane crash." (11.51am) (This message was the first to mention the correct number of casualties – after this point, all messages reported six casualties.)

Considering an appropriate point for intervention from official information sources, it may be the case that information that is released too early in the phase will be treated as too "elastic" and open to change. We have all experienced effects similar to this when news stories break on traditional media – for example a shooting episode reported on television news. Numbers of reported casualties often vary – sometimes wildly – over time until an accurate number has been established.

As the public begin to engage emotionally, some of the messages take on what can be considered an almost ritualistic quality. Examples are:

"R.I.P to all those who died on the plane crash in Cork #prayingforthem"

"Thoughts with all the People in this Morning's Air Crash in Cork Airport."

"Very sad news in Cork. Thoughts with the families of the victims."

Eventually, as the news is digested, people begin to introduce suggestions or points of view that pertain to the event. In the following examples, we can see how the posters refer to external knowledge:

"That air accident in Cork two missed approaches then divert the norm - three attempts considered potentially fatal always"

"Location of Cork airport was deemed unsuitable by expert report 50 years ago due to 'prevalence of fog' - http://bit.ly/gq8fCP "

The second example links to an external web site. Figure 8 illustrates the information being referenced.

Figure 8: External information considered relevant to the Cork air crash.

Conclusion

This proposed analysis using SA categories makes a convincing case for the changing quality of Twitter messages over time. However, it is only a start and it will be necessary to develop a more thorough understanding of how individuals use Twitter to share information. Indeed, given the relative infancy of Twitter as a form of social media, it is likely that any understanding achieved will require modification over time as use of the medium continues to develop. Furthermore, as suggested above, tomorrow, it may be a completely different social media application that is considered *de rigeur* and a different understanding will be required.

What is almost certainly the case, however, is that various types of social media will be continue to become more and more important as a mechanism for sharing and seeking information. This means that emergency planning agencies which are currently somewhat ambivalent to the importance of addressing the spread of information via social media must in the future address this issue. It also means that the networks on which these types of media rely will become even more important in the future. If provision of network coverage continues to be as uneven as it currently is (for example, leading to Carlisle focus group members commenting on the patchy mobile phone network), then it will be impossible for future best practice for social media information sharing to be rolled out across the country.

f. Visualising social media in an evacuation

(NB – This work was conducted in conjunction with Vincent Schmidt (Senior Researcher, Wright Patterson Airforce Base Research Laboratories, Ohio, USA)

In this section we investigate the use of new communications and social networking technologies as a new strategic tool for first responders and evacuation managers, at a time when unprecedented opportunities for real-time communication in evacuation at street level are emerging [Preston et al., 2011]. Public information for warning of impending crises need no longer be transmitted in a `top-down' fashion and rapidly we have moved to a situation where public information is just one signal in an information market place. Victims and evacuees can now communicate with each other before, during, and after an emergency and gain real-time access to information. As a result, they may indulge in individual and collective strategic behaviour (by generating alternative information and rumours perhaps).

Such strategic decisions by evacuees can be analyzed to design safer and faster evacuations. In order to do so public information and planning needs to become interactive, dynamic and responsive. For example, it is plausible for emergency management agencies to collect information during a crisis (e.g. messages posted on social networking sites) and to use this, not only in managing evacuations, but also to intervene by posting messages, selectively targeting trusted sources, and modifying electronic signage. This would modify incentive structures in evacuation through acting on real-time information. This preliminary study examines the utility of visualizing geotagged text data, similar to that available through social media, as a tool for analysts, policy makers, first responders and crisis management personnel, and social scientists.

One way to promote this capability is to design visualizations for emergency management personnel that are capable of displaying relevant data about the contents and metadata within real-time social media messages. Such systems should summarize salient semantic points such that first responders could re-inject recommendations back to social media and emergency management communications systems in near real time.

The role of agents and computational models in crisis management has been considered by Chen and Xiao (2008) who consider that real-time information can give feedback resulting in the adjustment of plans by the emergency services. Innovatively, Nakajima et al (2008) have considered the use of ubiquitous devices such as GPS and mobile phones to build a multi-agent evacuation strategy for the city of Kyoto, whilst Ushahidi (2009) maintains up to date reports submitted by the public and makes available latest incident reports on their website to assist victims of the Haiti earthquake. There is also a large body of existing work on mathematical modelling of evacuations, (Ferscha and Zia, 2010), but very little work has been published on the role of feedback loops and social networks in evacuation. The use of real time intervention in social networking and communications technologies will result in more effective crisis management, making evacuations safer and faster. Ultimately, we will make recommendations to stakeholders as to the efficiency of different communication channels and control strategies arising from our simulations, providing a sound basis for policy makers and responders to strategize about intervention in communication and social networking technologies.

Dataset Preparation

The dataset used in this preliminary concept is drawn from the 2011 VAST Challenge, related to the 2011 IEEE Conference on Visual Analytics Science and Technology (IEEE VAST). The mini-challenge 1 dataset (Geospatial and Micro blogging - Characterization of an Epidemic Spread) is interesting to us because the data consists of a million uniquely identified records containing originator id, timestamp, geospatial information, and message text. This information is typical of social networking data obtainable from SMS text messages, Twitter, and other commonly used sources. Instead of using the data to solve the VAST challenge, our immediate interest is examining how this type of information can be effectively displayed to a specified end-user or analyst. To that end, 10,000 records were randomly selected from the original dataset. Visualizing a large quantity of

messages effectively was best accomplished by dividing the dataset into smaller and manageable message groups. We accomplish this by sorting the records by timestamp, then ID, Created at, Location, text as illustrated in Figure 9 below.

73,5/16/2011 :28,42.28818 93.33605, sick of hearing about the Oil Spill now like

464,5/4/2011 20:04,42.28523 93.44908, Isn't it weird that after all the hoopla about the TSA there was another 'near disaster' averted? Seems like it happens too much.

Figure 9: Selected Dataset Records

Groups of messages in a conversation were subdivided geographically, yielding finer detail for the analyst. The method used to divide the collection of messages is based heavily on the automated clustering algorithm developed by Schmidt [Schmidt, 2002] for pre-processing neural network datasets. Clustering geospatial data is a multistep process described in detail in Schmidt and Binner, 2011.

Visualizing the Data

Our primary purpose for visualizing geotagged textual data is to provide first responders and other analysts a mechanism for quickly identifying and responding to trends in social media data that indicate the status of a catastrophe or crisis. Good visualization of such data is expected to enhance an analyst's ability to quickly offer guidance to the appropriate authorities and catastrophe response personnel. The visualisation, presented here in Figure 18 explicitly divides the display into three sections; message relationships, geospatial information, and message clusters. Figure 10(A) shows the original data. The algorithm sorts the data (10(B)), then finds the difference between consecutive data points. The differences for this dataset are shown in 10(C). The algorithm slices the data at the positions where the difference is greater than twice the standard deviation of the differenced data. (The standard deviation is shown as a horizontal red line in this Figure). The observant reader will notice the "steps" in the sorted data of Figure 10(B) are located directly above the most prominent differences indicated in Figure 10(C). These are the same places the data cluster boundaries are created.

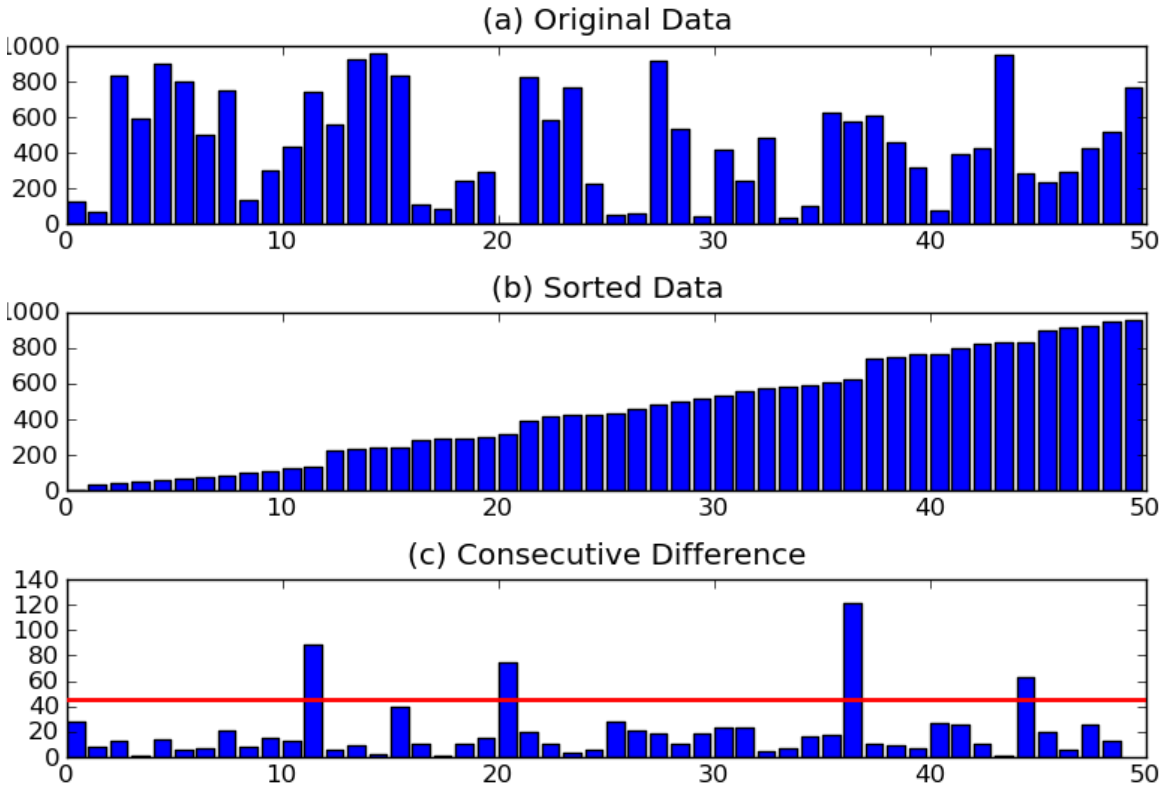


Figure 10: Automated Clustering Example

Figure 11 below, derived from the VAST data, represents the message relationships. It is a graph, partitioned into (automatically) geographically clustered sets of messages. Clusters are labelled alphabetically, starting with the letter "A" and messages within clusters are numbered from 0. In this figure, message nodes are linked in monotonically increasing time, such that A0 is time stamped before A1, which is time stamped before A2 etc etc. This arrangement of links is certainly not ideal, however. It would probably be more valuable to link the message nodes based on the semantic similarities of the contents of the message bodies. Work to revise the message graphs in this manner is in progress.

The centre of the figure contains a map of the geographic area of interest. A line connects the message graph to the mean location of all messages within that cluster. The actual position each message is indicated by the corresponding message label on the map, and the mean location of the message cluster is indicated by the placement of the cluster label on the map. We can optionally draw a line from each message node on the graph to its location on the map, but we found this additional information clutters the display and makes it tedious to read.

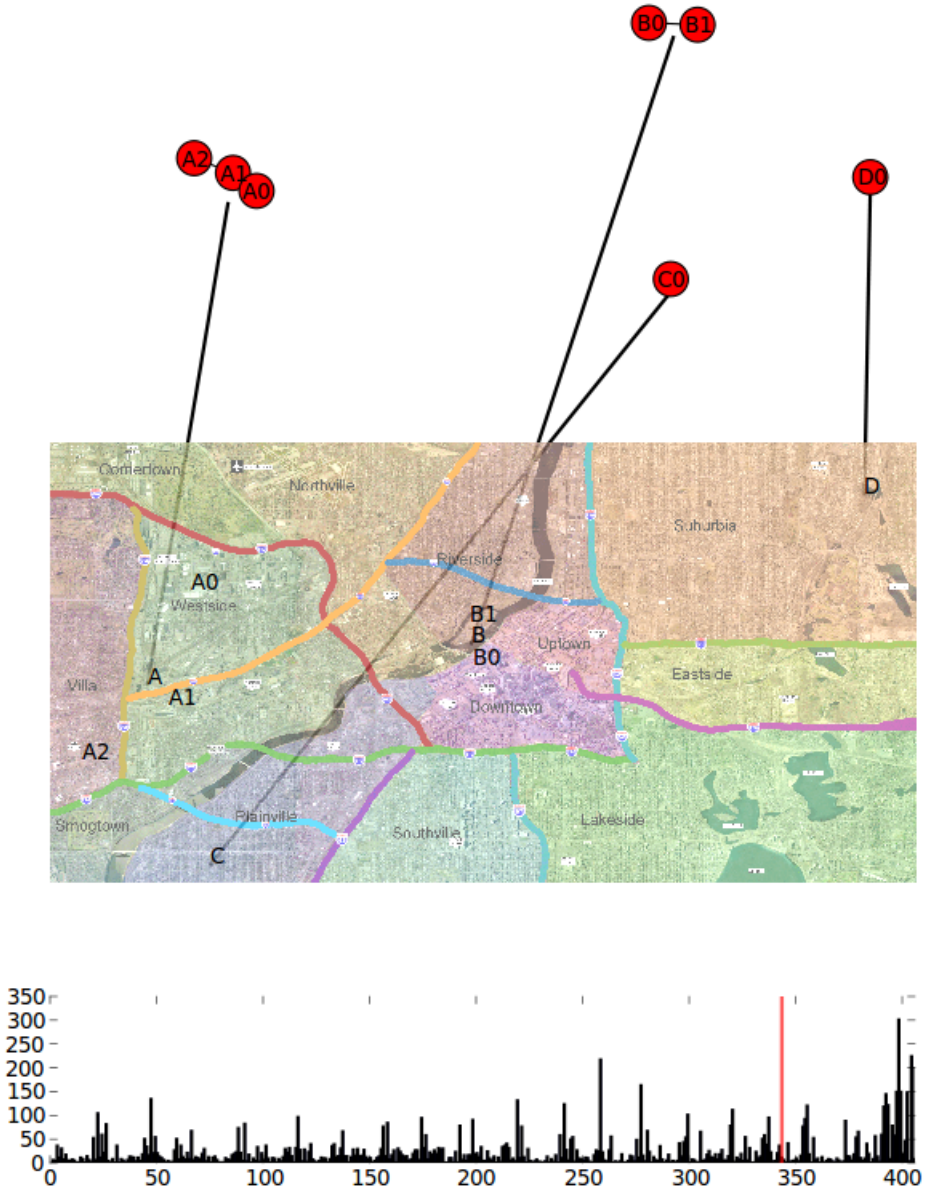


Figure 11: Visualising Geotagged Data

On the bottom of the figure is a histogram representing (on the X axis) the number of message clusters (actually 406 in this case, not explicitly indicated on the display), and (on the Y axis) the number of messages in each cluster. The red mark on the histogram indicates the message cluster currently being graphed and shown on the map. The user can change the currently displayed cluster by clicking the mouse on the histogram, or by using the cursor keys to move left or right by a single cluster. Hovering over a graph node at the top of the figure shows a tooltip containing the text of the selected message. Other visualizations are being added to the display as the semantic analysis and related development continues.

Conclusions

The visualizations we demonstrate are entirely exploratory in nature. We perceive a variety of uses for this basic type of interface:

- Fully automated operation might watch one or more social media streams in real time, indicating an alarm condition if a certain subset of words becomes frequent, or if a particular

location is referenced in a certain way. This would require the addition of flexible filters to the existing design. Such a model would be valuable to first responders as an additional watchdog for catastrophic events.

- Query design would allow a user to type a textual query, and the message graphs would be reorganized depending on the semantic contents of the query. A more structured interface would have to be added to make this utility viable, promoting a more visual geospatial search operation.
- Exploratory visualization occurs when the records are displayed using self-organizing algorithms. Deciding the "interestingness" of data is the grail of data mining, but a growing collection of algorithms and visual interfaces allow analysts and scientists to leverage these systems as tools more easily, especially when the automation can be trusted to identify and display certain trends without explicit interaction.

Our future plans include the incorporation of a variety of semantic algorithms, permitting the message graphs to be connected in more meaningful ways. This enhancement will also allow the graph clusters to be tagged to support semantic search operations. Adding a search tool or a watch-list of interesting terms would enable the utility to be used to display the results of simple searches. The ultimate goal is far more important than the mere display of message data on a graph or map. The ultimate objective is to create a reliable tool that allows first responders and others to leverage social media to protect the public at large. The testimony of the value of such a tool occurs when those who use the prototypes designed for their work areas are able to claim these devices and visualization are directly responsible for lives being saved.

g. Deploying emergency personnel in evacuations and crisis

(NB: Based on Smyrnakis & Leslie, under review; Smyrnakis & Leslie, under review)

Allocation of resources with multiple attributes

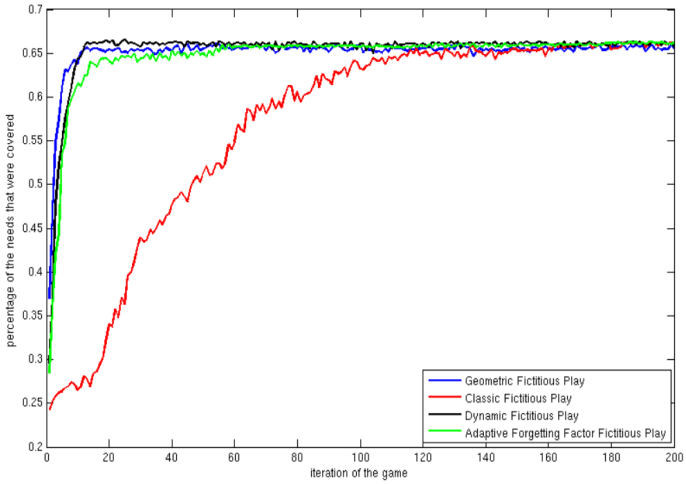
We also consider a game theoretic approach to the problem of resource allocation in disaster management. The model that we had studied until now included groups of agents with one attribute, e.g. ambulances. In particular we simulated the case where a natural disaster has happened (an earthquake for example), and because of this many incidents occurred simultaneously in different areas of a town. In each incident a different number of people is assumed to be injured. The town has a specific number of ambulances available that are able to collect the injured people. The question is then how to allocate these efficiently. The game theoretic model sees the ambulances as players in a multi-player cooperative game, who communicate with each other, and who among them try to find the best allocation.

In response to comments made at the previous meeting of the Dfuse Advisory Board we have extended this model by considering cases where the agents (ambulances in the previous scenario) can have more than one attribute. An example can be a scenario where policemen and firemen should be deployed in different areas of the town. We assume that some of the policemen are qualified also to help firemen to stop a fire and some firemen are also qualified to help policemen. Another scenario might be one in which the resources are vehicles which can either transport say equipment of emergency personnel/rescuers. We extend our initial model to include two attributes by updating the utility function of our initial scenario in order to include multiple resources which made the optimisation problem more complicated.

We used various algorithms from the game theoretic literature and combined then with two decision-making rules in order to study their impact to the resource allocation outcome. Our key finding indicates that by increasing the computational demand of the algorithms less communication is required in order for agents to coordinate. Nevertheless there were allocations where the simple algorithms performed better.

Figure 12 depicts the results of various learning algorithms in a scenario with 3 incidents and each of them had different needs to one of two available resources. Then the agents that should deliver the resources had to coordinate and choose the most efficient allocation to these incidents.

Figure 12: Changes over 200 iterations

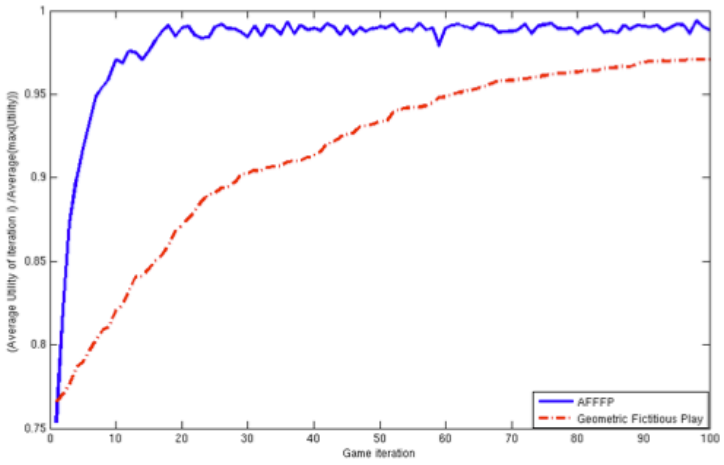


Average percentage of resource requests that were covered by the algorithms' proposed allocation. The results depict the changes over the 200 iterations of the algorithms, averaged over 200 different trials. Each trial contained 3 main incident areas that the firemen and the policemen could be allocated to. In each trial the needs of an area to firemen and policemen were chosen independently.

Game Learning Algorithms

Since resource allocation (such as the assignment of emergency services to emergencies) can be described as a potential game it is important to design learning algorithms that can converge to an optimal solution in these games. The canonical example in game theoretic learning algorithms is an algorithm referred to as "fictitious play". However fictitious play is founded on an implicit assumption that opponents' strategies are stationary. We have developed two novel variations of fictitious play that allows the use of a more realistic model of opponent strategy. The first one uses a heuristic approach, from the online streaming data literature, to adaptively update the weights assigned to recently observed actions. The latter one uses Kalman filters to predict opponents' strategies. Results from our simulations (see figure 13) show that both algorithms result in better solutions, when they are compared to the classic fictitious play algorithm.

Figure 13: Performance of game learning



Performance of game learning (adaptive forgetting factor fictitious play algorithm) in the so-called vehicle target assignment game.. The figure shows the obtained utility of the assignment as the iteration progresses.

h. Using disaster education to prepare the public for city evacuations

(NB: Text from this section can also be found in Preston, 2012)

Using information from the cities, social media and historical disaster education materials we considered the various methods of preparing the general public for city evacuations. In particular, we focussed on the equity considerations which are important when producing a disaster education campaign. Using pedagogical theory from education we firstly classified disaster education into six pedagogical 'types' referring to historical examples. By pedagogical we refer to the types of teaching and learning which are implicit in different forms of disaster education (Preston, 2012). We then examined the ways in which different pedagogical forms of disaster education might have implications for equity in terms of both the reach of disaster education and the assumptions made about how people might act (Preston, 2012; Kolokitha and Preston, 2012). Finally, we took a contemporary example of disaster education (social media in the Fukushima disaster) to consider the extent to which these new techniques allow policy makers to overcome some of the disadvantages of previous forms of disaster education.

1. Pedagogies of preparedness

'Disaster Education' is delivered to citizens in various ways including leaflets, public information films, notices and warning sirens, television and radio broadcasting, social media, school curricular, family and community learning and cell phone messaging. Through these media messages citizens prepare for various disasters, consider what they would do in a disaster and think about how they would respond. Because the methods used in informing citizens do not, on the surface, appear educational the ways in which preparedness for disasters is transmitted to citizens is often conceptualised through advertising or public relations models of information transmission. Although these models provide some purchase on the transfer of preparedness knowledge, a superior model for preparedness is a pedagogical (or andragogical in the case of adults) one. That is, rather than giving instruction they also engage individuals in learning about emergency situations whether in preparation, response or recovery from a disaster. Implicitly, they are based on models of how individuals learn. Preparedness campaigns aim not only to alter individual cognitions concerning emergencies but individual behaviours, the ways in which they make calculations of costs and benefits of following actions or not, their emotions and even their sense of personhood as a citizen. Various pedagogical devices are used in achieving this and there are various methods by which pedagogies can be classed:-

i. Banking and didactic pedagogies

Banking and didactic preparedness pedagogies are constructed on the basis that they are not intended to be used except in the event of an actual emergency. They exist as a series of didactic instructions or images. These can be delivered in a classroom context or in the home. In many cases it is implied that that citizens are not expected to read, or refer to them in advance but simply to be aware that they exist and to store them. There is a degree of subliminal awareness in the banking of these pedagogies as their very existence is to produce an awareness of at least the possibility of a crisis. 'Preparing for Emergencies' (HMSO, 2004), a booklet issued to the entire United Kingdom population to 'prepare' them for multiple types of disaster was an example of this type of pedagogy which was to be kept in a 'safe' place. These 'banking pedagogies' are also found on airline emergency cards which are based around bodily and spatial manipulation. The body is (often schematically) shown in various positions in order to stress the kinds of manipulations which should be followed in the event of an emergency. In the event of a CBRNe attack this might include ducking, falling to the floor or crouching behind a surface or running in order to reach cover or huddling.

ii. Construction kit pedagogies

Construction kit preparedness pedagogies are designed on the basis of DIY (Do it Yourself Instructions) providing guidance which is to be interpreted and acted on by the individual in the event of a crisis. The purpose is not to provide 'banking' information but to aid citizens in constructing their own shelters and equipment for survival. Construction kit pedagogies apply to the physical environment and are concerned with construction of a shelter, the use of duct tape in a chemical or biological incident or the storage of food and water. In these construction exercises, simple schematics are used in order to encourage the following of set procedures in building a shelter. For example, in the booklet 'Protect and Survive' (1980), which would have been issued (in some form, possibly as newspaper inserts) to homes in the United Kingdom in the event of a forthcoming nuclear war instructions are given for the construction of a basic home shelter (a 'fall out room' and 'inner refuge') to be constructed from doors, sandbags and other household furniture.

iii. Affective

Affective preparedness pedagogies are not designed to deal with the cognitive processes or behavioural skills necessary for protection but rather are designed around the principle that emotional labour is involved in preparedness. The effects of trauma, acceptance of war and the emotional upheaval for children of disaster are concerned with enabling emotional change or management. Often this means 'facing up' to the 'reality' of what has happened and affective pedagogies are considered to stimulate cognitive and behavioural changes in individuals. For example, the civil defence film 'Let's face it' (FCDA, 1956) was designed to change attitudes towards surviving a possible nuclear attack on the United States away from passivity or fatalism towards a positive emotional attitude to preparedness. This was in turn designed to persuade Americans to actively engage with civil defence efforts.

iv. Family and community learning

Family and community learning pedagogies make use of existing societal structures, such as the gendered division of labour, as pedagogical levers. The ways in which families or communities are employed in these pedagogies is complex and rarely is 'group learning' the pedagogical technique employed. To start with families, division of labour is implied which is often formally gendered or age related. Men can be portrayed in a construction role, taking on manual tasks or acting as 'head' of the preparedness activity whereas women are depicted in a caring role or acting in food storage and preparation. Sometimes these gender roles are slightly subverted in a proto-feminist fashion, but this is the exception rather than the rule. Community learning is a less common strategy as often the family is regarded as the notional unit of preparedness planning at least in the United Kingdom and United States. In the construction and potential habitation of fallout shelters in the cold war family and community learning techniques were employed. The cold war instructional document 'The Family Fallout Shelter' (Office of Civil and Defense Mobilisation, 1959) shows the 'Father' constructing the fallout shelter from concrete blocks in a basement whilst the 'Mother' is responsible for childcare. This reinforces the existing gendered division of labour. Similarly, the short film of a similar era 'Occupying a Public Shelter' (Office of Civil Defense, 1965) shows both gender segregated activities and how a community of shelter inhabitants learns to live together in a shelter during an atomic attack. The emphasis in the film is on 'community activities' (collective singing, exercise classes) and on pro-social behaviour.

v. Performance pedagogies

Certain preparedness pedagogies utilise tacit performance theories and dramaturgical techniques (Davis, 2007). Rehearsal of an actual emergency may have several pedagogical purposes. Rehearsal is used to routinise and familiarise individuals and families with preordained rules of behaviour. This is not only to lock in behaviours so that they become engrained into an individual's habits but also to attempt to remove affective or cognitive processes that may prevent action from being undertaken. Performance also enables individuals or groups to reflect on what has taken place and to consider the ways in which future enactments might be improved, with the aim that the actual 'performance piece' in a disaster is optimal. 'Performance' is additionally an appeal to audiences wider than those taking part in the preparedness enactment. They are designed to make observers reflect upon what is taking

part and consider what their own role might be in these exercises. Although these exercises were common in the cold war in contemporary contexts they are increasingly used to rehearse disaster scenarios by the emergency services.

vi. Public pedagogies

Public pedagogies take place in '… spaces, sites, and languages of education and learning that exist outside schools' (Sandlin and Burdick, 2010, p. 349) in particular domains of popular culture which are not frequently considered to be an educational arena. In terms of preparedness, popular cultural forms can embody lessons about preparedness in a reflexive manner. For example, a number of contemporary movies are concerned with a 'zombie apocalypse' where a virus means that the 'undead' overwhelm the living who fight for survival. These films include crude lessons on personal preparedness. However, they have in turn spawned a real group: the 'Zombie Protection Initiative' (ZPI) who not only organise (ironic) 'zombie preparedness' classes and initiatives in the United States but who also support real preparedness education initiatives organised by FEMA (Federal Emergency Management Agency).

2. Disaster education and equity in Nuclear and Radiological disasters

The concept of 'tacit intentionality' is useful in considering equity in disaster education. Tacit intentionality refers to how unquestioned assumptions in planning disaster education may lead to implications for equity. For example, in terms of the design of preparedness materials for public education in the Cold War the guidance was (largely) designed with agentic, suburban families in mind who would have good access to shelter in a private dwelling. This information was to be distributed to the general public via print media, leaflets and television. This produced an ideal type of survivor (see table 3):-

Table 3: Tacit intentionally and survivors / victims from disaster education in the Cold War

Victims would be…	Survivors would be…
Urban	Suburban / Rural
Living in flats / bungalows / caravans	Living in detached houses
Not able to make use of inner rooms / cellars	Able to make use of shelter in their own homes
Extended family / single	Traditional nuclear family
Dependent on state	Privatised
Passive and unresponsive	Active and agentic
'Other' / not English speaking	British / English Speaking

Similarly, reliance on social media for disaster education in a current crisis would produce ideal types of survivors / victims. Social media privileges those who are technologically literate, connected, resource rich and responsive who are also likely to be of a particular demographic group (see table 4).

Table 4: Tacit intentionality and survivors / victims from disaster education relying on social media in a radiological disaster

Victims would be…	Survivors would be…
Fixed (depends on nature of disaster)	Mobile (depends on nature of disaster)
Technology poor	Those with access to technology
Isolated	Social media / social capital connected
Old media reliant Rumour reliant	Transmedia literate Information reliant
Resource poor	Resource rich
Slow to respond	Agentic
Unhealthy	Healthy

Moreover, despite the enlightened technologies used in social media with enormous potential for crowd sourcing (Preston et al, 2011), there has not necessarily been a similar shift in social attitudes. For example, the Fukushima Daiichi radiological disaster of 2011 was reported widely in the world media. It arose from the unprecedented earthquake and tsunami off the cost of Japan in 11th March 2011. This resulted not only in the Fukushima plant being disrupted by the earthquake but also from flooding from the resulting tsunami. The resulting effects on the reactors were both planned and unplanned releases of harmful radioactive material into the environment. As a result of this the Japanese government quickly gave instructions that individuals within a 20 kilometre radius should leave immediately and those within a 20 to 30 kilometre radius should shelter in place. The resulting release of radiation was so severe that it is considered that the 20 kilometre area around the plant may never become habitable. The Fukushima disaster was rated at the top 'level 7' (major accident) on the International Nuclear Event Scale which gives it similar significance to the Chernobyl disaster in 1986. Social media, and transmedia, was considered to be particularly influential in terms of the Fukushima disaster when compared to previous nuclear accidents such as Three Mile Island and Chernobyl. Only four months after the disaster Google produced over 73 million search results on Fukushima and there were over 200 thousand results on Google news. It is apparent that Fukushima was probably the world's first transmedia major radiological disaster as information flowed between social media, photograph and video websites, blogs and official news media.

In an analysis we conducted of the Twitter archive from Twapper-Keeper (twapperkeeper.com), a user generated archive that saves hashtag messages) from all messages from the period saved with the keyword 'Fukushima' and related terms, however, it was discovered that there were a number of negative and hostile messages concerning the disaster and its effect on Japanese people. Indeed, these were very similar to the negative stereotypes of Japanese people which were circulated in the Second World War. This shows that despite the 'revolutionary' nature of social media its anonymous and instant nature may lead to negative outcomes in terms of balanced portrayals of events.

3. Implications for future disaster education campaigns

Our analysis of disaster education shows that there are various pedagogical (teaching and learning) techniques that can be used in informing and warning the public. This is a different method to classifying forms of disaster education than by media type. For example, seemingly different media types (leaflets, television broadcast, information on the internet) employ similar pedagogies (didactic), Similarly, very different types of media (face to face and social media) may employ similar pedagogies (for example, community learning). We would argue that pedagogical coverage (by the

different ways in which people learn) as well as media spectrum coverage (by the type of media) is important in educating the public for disasters.

In addition, our work has shown that different forms of disaster education have differing implications for equity. Although a completely 'equitable' form of disaster education is unrealistic the tacit assumptions of disaster education should be examined. As our Twitter analysis of the Fukushima crisis showed new media does not necessarily change attitudes.

i. Conclusions for policy and practice

- Social media presents a challenge for city evacuation policy. It is most effective when information is accurate and timely, when the city has an orientation towards social media; when it is used in conjunction with other forms of media (in terms of increasing both the proportion of the population informed and equity) and when it can be used to source outlying information. However, if agents are 'over-informed' it may result in congestion and jamming; it has a selective demographic effect; it is less effective than old media as a mechanism for an initial warning.
- Different cities have different orientations to using social media in an evacuation and this should be considered in city wide social media strategies.
- Network coverage is an issue in some regions if cellular communications are to be systematically used in engaging with the public in an evacuation.
- Old media is still the most effective medium for immediately warning and informing the general public.
- Simple models suggest a three-way split between Radio/TV as rapidly seeding a large part of the population, direct social contact (e.g. by phone) as generating a rapid second wave (with concomitant strain on communication networks), and a minor role for social media. This ability to synchronously inform the public through old media is likely to reduce as our interaction with information diversifies.
- A critical "realize-and-relate" timescale is the interval between an alert appearing (for the first time) on an already switched-on TV/Radio and a direct communication by the media consumer to another person. During the daytime this will possibly yield a public that is majority informed on a timescale comparable to the realize-and-relate duration and has implications for the traffic capacity of our communication networks. Further empirical study of this timescale, and how it can be modulated, is supported by our work.
- Interactions between 'old' and 'new' media are important in terms of not only the spread of information but (potentially) in terms of the ways in which content is relayed (transmedia).
- There is huge time sensitivity in terms of the effectiveness of warning and informing the general public. There remains the problem of warning the population in the middle of the night when traditional warning systems may be more effective (sirens, door to door) if an evacuation is necessary.
- The issue of how opinions are formed on social networks is central in discovering how this may impact upon city evacuations. It is interesting to look at how prior beliefs evolve as individuals swap information on social networks (noting a duality between coupled urn models and models of Bayesian inference by a population) this becomes both a mathematically rich and relevant topic for further investigation
- For social media to be of use by citizens in evacuations information should ideally be both accurate and timely.
- In an evacuation it is plausible that social media communications will follow situational awareness categories over time (Perception, Comprehension, Projection) and that this has implications for engagement with social media by authorities.
- Communication between agents does not always help. In one of our evacuation simulations if the number of communicating agents exceeds the optimal ratio then agents are `over-informed' and frequently change their minds during the process, slowing down the overall efficiency of the evacuation.
- In a simulation of the evacuation of a UK city, communication between agents caused congestion.
- Using statistical methods we can identify outliers in social media in evacuations. This is useful both for identifying novel and troublesome social media outputs.
- For emergency response to be effective in a city evacuation algorithms used to allocate emergency personnel to events should be changed according to the nature of the situation
- Disaster education in an evacuation / invacuation should cover a wide pedagogical spectrum to take into account different types of learning.

- The use of social media for disaster education may be technologically progressive but is not always progressive in terms of equity and representation.

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