Impact of personal communication networks on emergency evacuation times

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ABSTRACT

Any large-scale anthropogenic or natural disaster, such as a chemical spill, terrorist attack, fire, hurricane, or flooding, impacts human behavior and vehicle movement in the affected area. The response of the affected population is driven by available information about the event. However, inattention to public announcements via vehicle radios, listening to other audio media, and an initial lack of reliable information in the chaotic moments immediately after a disaster will result in an uniformed or misinformed public. For example, the sudden and unannounced nature of a disaster often results in uncertainty with regard to geographic location and extent of the event, resulting in inaccurate information worsened by inattention to public communication. Therefore, the uncertainties and lack of attention to the initial public announcements exacerbate the initial emergency response effort. The question of how the communication network might enhance or diminish the proliferation of information that would facilitate the evacuation of the population must be addressed. Consequently, the authors created a simple model of interpersonal communication via cell phones and their respective personal contact networks to begin a study of the role and impact of information as it passed rapidly through personal communication channels as individuals share in the context of initial repetitive public information during an evolving disaster response. The model demonstrates that increasing the access to mobile phones can significantly improve the speed and degree of success of evacuations.

Key words: disaster site evacuation, cell phones

INTRODUCTION

A large-scale catastrophic event such as the 9/11 terrorist attack can be a very chaotic scene with individuals attempting to evacuate, curious spectators and losters flocking to the area, disinterested individuals merely trying to pass through, and emergency response personnel attempting to proceed to the event. The 9/11 disaster killed building occupants, passengers, flight crew, and emergency responders (ERBs) and has left its historical mark. However, almost every community has been affected by a disaster on a smaller scale that often replicates the characteristics of large-scale disasters. These can be varying degrees of congestion, chaos, uncertainty, confusion, lack of effective communication, injuries to victims, and sometimes even injuries to ERBs and curious bystanders.

Although public communication plays an important role in traffic control through radio traffic reports, informing individuals of congested areas and alternate routes, alternate communication paths are becoming increasingly significant. For instance, some vehicles are equipped with global positioning system (GPS) devices that monitor and warn of traffic congestion. Aftermarket GPS devices and smart phones with remote Internet access and appropriate software are used for the same purpose. Finally, interpersonal communication vectors (verbal and texting) via cell phones and their respective personal networks are added to this mixture.

Furthermore, just as cell phones have improved communication, other multimedia devices, such as satellite radio, CD players, and iPods, have increased initial public awareness of catastrophic events. In addition,
initial inattentiveness to the radio should it even be on, will cause initial uncertainty—a "what was that about?" scenario, where the listener only hears part of the announcement.

Consequently, the very nature of a catastrophic event (unannounced and sudden) results in initial uncertainty and lack of credible public communication. The partial truths of initial public announcements exacerbate the spread of rumors through the degree of doubts, need for truth, and partial believability. Existing work in this area has focused on the impact of a disaster on physical infrastructure and networks, on the communication between EIDs, on the public announcement of the event, on the expectation of government response, or on the information exchange following emergency situations. Therefore, it is the object of this study to focus the geospatial communication between the victims, unaffected but interested public, and the comprehensive impact of various communication networks on their behavior and the management of the site.

A disaster occurs when an extreme event exceeds a community's ability to cope with that event. Natural and human-caused disasters leave both long-term geospatial and human scars. Although air- and space-borne imagery and resultant geospatial information products for each of these events before and immediately after the event can provide physical details, the ultimate outcome of the scenario immediately following a disaster is difficult to predict. It is the broad goal of the emergency management to reduce the loss of life and property and to mitigate the impact from ALL HAZARDS, including natural disasters, acts of terrorism, and other human-caused disasters. Emergency management consists of preparedness planning for and response to major disasters. However, such emergency management efforts are often hindered not only by the lack of access to information and insufficient communication between technology providers and users but also by the inability to fully comprehend the magnitude of the event, its immediate impact, and the final outcome. Although emergency staff attempt to recover from ongoing disasters, as in the case of flooding, fires, or aftershocks events, the loss of life and property, further injuries, and mental stress (victims and responders) still continue.

Additionally, our work on the propagation of rumors through networks has shown the influence of the network size and topology on the spread of information propagation. In the event of a large-scale catastrophic incident, such as a multiple vehicle accident, fire, chemical spill, hurricane, tornado, flooding, that affects multiple vehicles, roadways, social structure, and personal safety for an extended duration, human behavior (response) can be affected by both public and private communications. Unfortunately, as the event unfolds, initial public communications can be lacking in detail, inaccurate, and met with skepticism or lack of comprehension. In fact, ineffective rescue after Hurricane Katrina was in part caused by inaccurate reporting, rumors, and the breakdown of telephone communication systems. Interestingly, interpersonal communications, although less accurate, may have a higher credibility rate (N. DiFonzo et al., unpublished data, 2010) and consequently a greater influence on behavior.

Rumors are an ever-present fixture of our present life space and they contribute to behavioral outcomes. Moreover, in the context of an unfolding disaster, they are instrumentally relevant; they are often perceived as useful information and fill the void for the initial lack of accurate and complete public announcements. Indeed, noted sociologist Shourouk (2011) dubbed rumors, "improved news." With the proliferation of cell phone and their social networking applications, personal communication networks exist, which allow the rapid spread of rumors or partial truths.

**Methodology**

Simply stated, networks are a collection of points (nodes), and lines (edges) connecting these points. In the context of this study, the nodes are vehicles and the edges are the communication channels between these vehicles. In the recent work of B. P. Brooks et al. (unpublished data, 2011), it was pointed out that although other models exist for rumor propagation, all
those start with equations for other systems such as epidemics or the behavior of gas molecules. Consequently, we used models developed specifically for rumor propagation. Networks of various topology and sizes were generated using programs developed in MATLAB. In contrast to earlier models, which assumed continuous connectivity, the models will use intermittent connectivity as applicable to phone conversations in addition to duration, probability of connectivity, believability, and degree of propagation.

Furthermore, superimposed on this person-to-person network, we modeled the existence of public broadcasting. The latter, notification through car radio, will in turn be dependent on whether the radio is on, the frequency of the announcement, the accuracy and believability of the announcement, and the attention of the listener. In this study, if a vehicle's radio was on and the announcement heard by the occupants, the vehicle responded immediately to the announcement and proceeded directly to its respective assigned evacuation site.

Consequently, interpersonal network theory was combined with agent-based models (ABMs) of how information is spread. ABMs are well suited for complicated systems such as an unfolding disaster and have the advantage over other methods in that aggregate results are produced by modeling smaller bits and allowing the agents to "sort it out." Consequently, experts can be consulted to create rules for realistic behavior of single agents. It may be impossible to create equations that simultaneously govern all factors in a disaster; however, this issue is avoided with ABMs because rules are created for individual agents. The resultant holistic, almost-humanistic, behavior of these agents is a function of the interaction of each individual agent with other agents and with the environment that in turn acts on the individual agent. ABMs have been developed for a number of unique situations in the last two decades, including epidemiology, forest fires, building evacuations, civil violence, development of minority opinion and creation of terrorist cells, asymmetric warfare, flow management of resorts and department stores, organizational and stock market behavior, bank fraud, economics, and many aspects of nature and chemical systems.

We created a basic traffic model shown in Figure 1 with 900 vehicles, vehicular movement on eight roads running in a north-south or east-west direction. Traffic lights control each intersection, in which vehicles have the ability to turn in either direction or to continue in their original direction. U-turns were not allowed. A randomly generated disaster site (not shown) was generated at the beginning of each simulation. Communication networks, both public and private, were added to the vehicles in the model. The model was developed in NetLogo, a multiagent programming platform with geographic information system (GIS) capabilities developed at Northwestern University Center for Connected Learning and Computer-Based Modeling. Its GIS capabilities allow the import of maps and GIS data sets and the ability to easily create networks and classes of agents. Consequently, networks of various topologies and sizes (effective agent connectivity) can be created and imported into NetLogo. At this stage, however, we merely created a small area traffic map using a simple computer-based drawing program.

Personal communication networks were created in MATLAB and generated to have an expected average geodesic distance between nodes and a measure of connectivity as measured by the clustering coefficient. This coefficient measures the degree of connectivity of groups. "Friends" on a personal communication network are generally considered a "small world" network and have clustering coefficients around 0.2-0.3. This means that an individual talks to two independent people on their network, those two individuals have a 20-30 percent chance of knowing each other or being "connected."

The networks were created with connections at 0, 50, and 100 percent and clustering coefficients of 0.0, 0.2408, and 0.2446, respectively. Hence, the 50 percent network was created by first creating a small world network of 100 nodes and then adding the remaining 100 nodes with edges absent. The subnetwork of connected nodes was randomly generated to simulate a real human communication network using a modified version of the standard preferential attachment algorithm. This new network generation algorithm randomly generates networks with the desired clustering.
Figure 1. Small neighborhood disaster site with roads shown in yellow, parking lots (evacuation sites) in brown, and grass and water in green and blue, respectively. Vehicles are shown on the roadways in black.

The allowed duration of a cell phone call, or the inverse of the call frequency, was set at 0.5, 1, and 2 minutes. Calls over the communication network started as soon as a vehicle encountered a disaster site. It was assumed that if a vehicle receives a call from another vehicle, the recipient vehicle would proceed directly to their assigned evacuation site. As more vehicles were informed of the disaster site and its location, either by direct sighting or through a call, they, too, would avoid the site and proceed directly to their assigned location.

The remaining predictor variable, time between public radio announcements or again the inverse of the frequency, was set at 1, 5, and 10 minutes. The first broadcast occurred to all vehicles at an initial time equal to the time between announcements, i.e., 1, 5, and 10 minutes, set at the beginning of the simulation. Hence, for the 10-minute interval, there was a 10-minute delay with no public announcement resulting in essentially only one announcement during the simulation. Whereas the 1-minute interval resulted in only a 1 minute delay before the first announcement followed by an announcement every minute.

Figure 2. Multiresponse plot of the overall LS means to the predictor variables of degree of evacuation of 25, 50, and 75 percent for the vehicles.

STATISTICAL ANALYSIS

A least-squares (LS) analysis was performed on the response variables, time to degree of evacuation of 25, 50, and 75 percent for the vehicles. It was found that these variables are highly correlated and also demonstrate a linear behavior in the model (Figure 2). The predictor variables of public announcement frequency, time between calls, and percent of networked were all significant at the 5 percent level as determined by t ratios (all p-values are < 0.0001). The second order of these variables with percent of networked was also significant but not reported at this time. The most significant predictor of 50 percent and 75 percent evacuation of the vehicles was overwhelmingly percent of networked, but at the 25 percent evacuation level, it was time between calls with percent of networked a close second.

RESULTS

The time to degree of evacuation of 25, 50, and 75 percent for the vehicles was used as the response variable for this study. Evacuation was defined as a vehicle going to and parking into a predetermined evacuation site or parking lot. The evacuation sites were randomly assigned at the beginning of each model run, as well as the location of the disaster site. The traffic speed in our small neighborhood was set a nominal value of ~30
with acceleration and deceleration at intersections. The number of iterative steps was dependent on the settings of predictor variables and ranged from about 6,500 to more than 16,000. The later value was in the absence of public announcements and personal communication network where evacuation happened only by direct vehicle observation of the disaster site. This is termed the “Baseline Case.” With this speed and distances for our microcommunity, the total evacuation time in the absence of public announcements and personal communication networks was 18.3 minutes. The relative improvement of community or area times to evacuate to 75 percent was recorded and is given in Table 1. Hence, in this preliminary study, we observed the relative impact of the personnel communication networks on disaster site evacuation.

Consequently, this allowed relative behavior and effects to be determined with calibrated times to follow as extensive models are developed. In this preliminary study, we found several interesting observations.

The public broadcast times were made at 1, 5, and 10 minutes and then at that interval for the remainder of the simulation. Hence, the 10-minute broadcast was made only once during the simulation, the 5-minute announcement a couple of times, and the 1-minute broadcast several times. The effect of these broadcasts is clearly shown in Table 1.

Furthermore, just because a broadcast is made, does not mean that it will be heard and then heeded. Consider that the driver may not have the radio on, may be listening to another audio source such as a CD, iPod, or satellite radio, may not be attentive, may be channel “hopping” and miss the broadcast entirely, and/or may not react if it is heard. In this simulation, we assumed that the vehicle has a 5 percent chance of actually hearing the broadcast, but the vehicle responds if the broadcast is heard. This was estimated from the consideration of the proportion of drivers actively listening to the radio at any one time. Although there are many alternate audio devices available for in-vehicle use, according to a recent report,11 –70 percent are radio “listeners” during the morning commute and during the day with the percentage dropping during the evening commute.

<p>| Table 1. Impact of public broadcast and percent of networked on time to 75 percent evacuation |
|-----------------------------------------------|-----------------------------------------------|</p>
<table>
<thead>
<tr>
<th><strong>Public broadcast, min</strong></th>
<th><strong>Improvement to 75 percent evacuation for percent of networked.</strong></th>
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<tbody>
<tr>
<td>None</td>
<td>0</td>
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<tr>
<td>1</td>
<td>25</td>
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<tr>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
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</table>

Listeners are broadly defined from the active listener to someone who merely has the radio on. Consider, in addition that it has been reported10 that more than 50 percent of some drivers, depending on age, will text or e-mail while driving, and 67 percent of drivers admitted to talking on their cell phones.

However, the most dramatic effect in the model is the impact of the personal communication network. Although the percent of improvement to 75 percent evacuation as shown in Table 1 can be changed through alteration of probabilities and frequencies, the percent of improvement to 75 percent evacuation can be significant. We also considered the time between calls and the diminishing probability of making a repeated call. The impact of time between calls or frequency is shown in Table 2. This effect was measured as the percent of improvement over the Baseline Case. Although there is a decreasing effect on the improvement of the evacuation, it still does not dramatically impact the effect of the personal communication network on site evacuation.

<table>
<thead>
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<th>Table 2. Impact of call frequency on evacuation improvement</th>
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<tbody>
<tr>
<td><strong>Time between calls, min</strong></td>
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<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>0.5</td>
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<td>1</td>
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SUMMARY

An agent-based model was used to investigate the potential relative impact of a personal communication network and public announcements on disaster evacuation scenarios. The model shows the potential importance in terms of evacuation efficiency of a personal communication network. This is undoubtedly due to the attention that an individual pays to a "personal" phone call, the time or frequency these phone calls are made, and the reliability that is placed on a phone call from a known associate. Although at this time the output from the model is merely relative, it does indicate with stark reality the potential usefulness for a well-managed personal network in the time of a catastrophic event.

This study continues with the topologies and sizes of personal communication networks, such as random, small world, complete, regular, and family, coupled with realistic geospatial information and should result in the better understanding of the initiation, impact and control of congestion, and the resultant improved evacuation at a catastrophic event. This in turn will lead to opportunities for better site management, alternate site management policies, improved efficiency of emergency personnel (less time/personnel managing site traffic), and more personnel available for direct attention to victims of the disaster. The model demonstrates that increasing the access to mobile phones will significantly impact the percentage of successful evacuations. Hence, programs that provide subsidized mobile phones could increase public safety.

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