ANALYSIS OF VOLUNTEERED GEOGRAPHIC INFORMATION FOR IMPROVED SITUATIONAL AWARENESS DURING NO-NOTICE EMERGENCIES

by

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Analysis of Volunteered Geographic Information for Improved Situational Awareness during No-Notice Emergencies

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Dedication

In memory of our Brothers and Sisters in arms who made the ultimate sacrifice.

May God comfort your Family, Friends, & Comrades. May your sacrifices not be in vain...

Be thou at peace.

Acknowledgments

I would like to thank Dr. Nigel Waters, Department of Geography and GeoInformation Science, George Mason University, for his mentoring, coaching, and dedication throughout this research. You have invested your time and effort in supporting my research and your guidance has pushed me to be a better student, man, and father. You have encouraged me to seek out research that I not only find interesting and challenging, but research that will also have an impact on others. It has been a true pleasure to have worked with you and I will always be eternally grateful to you.

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ANALYSIS OF VOLUNTEERED GEOGRAPHIC INFORMATION FOR IMPROVED SITUATIONAL AWARENESS DURING NO-NOTICE EMERGENCIES

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During a terrorist attack, evacuees face uncertain risks when deciding which route to utilize while trying to evacuate. Immediately following an attack, information is very limited or non-existent. Emergency services personnel are responsible for finding and notifying evacuees of impending danger, and minimizing evacuation risk is crucial to limiting additional loss of life, especially in densely populated areas. One of the challenges for evacuees and emergency services personnel is sharing and collecting information. Recently, mobile phones and social media (e.g. Twitter, Facebook, and others) have provided a global platform for sharing information about terrorist events and a medium for emergency services personnel to collect Volunteered Geographic Information (VGI). It is highly recommended that Emergency planners use VGI to supplement their decision making, notification processes, and response and recovery. With over 5 billion mobile phones world-wide, VGI can potentially contribute data that supports risk modeling and evacuation planning. The mass adoption of mobile phones provides citizens and emergency personnel with alternate methods of communication (i.e. voice, SMS, mobile applications, and access to social media). GPS accuracy on mobile phones continues to improve which further facilitates planning and response by emergency service personnel. This research provides two models. The first model is a multi-objective, multi-criteria model that analyzes mobile phone location data and seeks to minimize risk encountered by evacuees and distance traveled. The study area for the first model is Manhattan, New York City. Risk and distance traveled is determined for the evacuation routes and is modeled in a Geographic Information System (GIS) to determine optimum evacuation routes. The second model analyzes social media to determine risk to evacuees during a simulated terrorist attack at George Mason University. Individual terrorists attacks are modeled and then combined based on time of incident. High-risk areas are modeled for multiple terrorist attacks providing first responders with increased situational awareness. The second model in this research improves situational awareness immediately following a terrorist scenario and the first model provides a multi-objective, multi-criteria method for reducing risk to evacuees. This research contributes to improved evacuation routing and visualization of risk during emergencies and increases situational awareness of first responders and citizens.

Chapter 1: Introduction

1.1 Motivation and Problem Statement

Immediately following terrorist attacks, citizens find themselves exposed to unknown risks and desire to find their way to safety. Following attacks in Madrid (2004), London (2005), Mumbai (2006 & 2008) many citizens turned to social media and their mobile phone to update friends, family and fellow employees on their status. Many individuals used social media to share what happened and where it occurred. Citizens in the periphery of the events may be aware that an incident(s) has occurred; however, they maybe unaware of what and where. These citizens often rely on first responders to usher them to safety or wait for traditional notification through television or radio.

1.2 Sharing Information Before, During, and After Emergency Evacuations

Traditionally, emergency managers relied on television, radio, and local warning sirens as methods of notifying citizens of an emergency or crisis event (Sorensen, 2000). Recent improvements to notifications include using the Internet and the Wireless Emergency Alerts (WEA), also known as the Commercial Mobile Alerting System (CMAS). WEA complements traditional notification services; however, WEA is not available on all mobile phones (Federal Emergency Management Agency, 2012a). In 2014, Next Generation 911 is expected to be available in the U.S., providing capabilities to send an SMS to 911 call centers (Selyukh, 2013). These are significant improvements to notification services and 911 call center capabilities; however, in 2011, the Red Cross found that over 80% of citizens expected national emergency response organizations to monitor social media (American Red Cross, 2011a).

During recent disasters and terrorist attacks, citizens have turned to social media platforms such as Twitter, Facebook, Flickr, and Instagram to share information with friends, family, and fellow workers. On the other hand, emergency managers have primarily used social media in a passive role, such as monitoring sentiment and increased situational awareness. One of the first full time operations centers in the United States was established by the U.S. Red Cross (Fox, 2012). The Red Cross opened its Social Media Digital Operations Center (DOC) and actively responds to calls for assistance via social media . The center monitors an average of 4,000 tweets per day.

1.3 Social Media and Emergency Evacuations

Social media and mobile phones provide a yet untapped source of data that can be harnessed. Fusing traditional remote sensing data with non-traditional crowd-sourced data provides and analyzing provide evacuees with an evacuation route is one method of minimizing risk during a crisis or emergency. Meier (2012a) presents benefits and challenges of using social media during and emergency include:

Benefits

- Many credible sources can provide information
- Social media can be used to measure sentiment
- Information gathering for citizens and first responders
- Messages are repeated
- Continuous contact with citizens

Challenges

- Content length maybe limited, leading to incomplete information
- Message can be manipulated once released

- It is important to gain followers prior to a crisis
- Increased messaging may cause network overload

Many of the challenges of using Social Media during an emergency also apply to other information sharing platforms, including news media, the Internet, etc. Another benefit of Social Media is that it provides an alternate method of information sharing, especially when power and communication outages occur. During the past decade, citizens have transitioned from relying on traditional communication methods to using mobile phones and social media during emergency and crisis events (Crowe, 2012). Emergency personnel have adapted to changes in mobile technology but have been slower to integrate Social Media into operations. One challenge with mobile devices is the need to recharge them; however, whether in developed or undeveloped countries citizens have adapted when power outages occurred. Immediately after the 2010 Haitian earthquake and after Hurricane Sandy in 2012, citizens setup charging stations to charge mobile phones which enabled citizens to communicate using their mobile phone (voice and SMS) and to post updates on social media sites (McCabe, 2010; Bergen, 2012). Social Media provides an alternate method for not only communicating with citizens, but for collecting information about a crisis, monitoring citizen' actions and inactions and respond accordingly (Mileti, 2010).

1.4 Application of Volunteered Geographic Information during Crisis Events

The term Volunteered Geographic Information (VGI), a term introduced by Goodchild (2007a), is geographic information that private citizens collect and submit primarily through the Internet. One of the primary concerns with government acceptance of VGI is that it is collected by 'un-trained or un-educated' personnel, unlike formal data collection by well-trained and well-educated employees. Using VGI usually provides more sensors than formal methods, enabling government and non-government agencies to fill the gap on outdated maps and to fill in spatial and temporal gaps in data for an area of interest.

Goodchild's assessment of VGI data collection, analysis, and mapping (e.g. OpenStreetMap) with traditional mapping (e.g. National Geospatial Intelligence Agency) is that the two are on opposite ends of a spectrum (Goodchild, 2007b). VGI is collected on much shorter timescales, horizontally organized in terms of its structure, constantly collected and cross-referenced, and it is hard to distinguish between consumers and producers of the data. On the other-hand, Goodchild (2007b) describes traditional mapping agencies as "top-down, authoritarian" entities that have existed for centuries. Their developers have formal education and training and there is a clear distinction between the expert and the consumer. Progress or change in the acceptance of VGI will be a democratic process that requires time, patience, and increasing resources (ibid).

There are over 6 billion people in the world and 5.9 billion mobile phones (The World Bank, 2012; International Telecommunications Union, 2013). These citizen sensors provide an opportunity to fills gaps in our data sets that our current remote sensing technologies rarely detect (Goodchild, 2007b). Using GIS to collect and analyze multiple sources of data during an emergency evacuation assists planners and decision makers with mitigation, preparation, response, and recovery (Cova, 1999; Toomey et al., 2009). Web-based mapping technologies have enabled more dynamic, transparent, and decentralized disaster response (Kawasaki et al., 2012). Crowdsourcing and harvesting geographic information has proven to be more beneficial to emergency response personnel than the risks associated with using this data (Goodchild and Glennon, 2010; Stefanidis et al., 2011). Social media has proven effective in modeling and visualizing the effects of disasters and other events across geographic areas (Stefanidis et al., 2011). VGI, such as social media, provides information that should be used to determine high risk areas within the evacuation zone in no-notice evacuations. Social media provides information analyzed, modeled and quickly shared, thereby reducing the time lag of notifying citizens during an event.

Quickly determining the what and where of no-notice terrorist attacks is critical to reducing risk to citizens and first responders. Citizens that are near the terrorist attacks often share information through Social Media providing spatial and temporal information about the incidicent(s) (Gupta and Kumaraguru, 2012). The Department of Homeland Security model for risk analysis is a function of threat (t), vulnerability (v), and consequence(c) (National Research Council, Committee to Review the Department of Homeland Security's Approach to Risk Analysis, 2010). Various models have been developed that accurately model risk from natural disaster preparedness; however, the task force did not find any evidence that other areas within the DHS model were accurately modeled. This methodology seeks to address risk in urban environments by modifying the current DHS risk model. Goodchild and others have addressed the concerns of accurate reporting when using VGI (Goodchild, 2007a; Goodchild and Glennon, 2010; Li and Goodchild, 2010). Goodchild and Glennon (2010) highlights the need for timely information versus the concern over accuracy of the data received.

1.5 Dissertation Organization

This research contributes to several key areas of Geographic Information Science including: network analysis, risk mitigation, and volunteered geographic information. Specifically, this research contributes by presenting a Multi-Objective, Multi-Criteria model for evacuation routing using mobile phone data during an emergency and introduces a model for visualizing risk and improving situational awareness immediately following a no-notice emergency using social media data. The following provides an overview of the remainder of the dissertation.

In Chapter 2, I provide a thorough literature review of social media and mobile device use in emergency evacuations. The concerns and challenges of using social media while protecting individual privacy are addressed. Finally, it provides an overview of the analysis of Volunteered Geographic Information to minimize risk during emergencies. In Chapter 3, I discuss the development and testing of a Multi-Objective, Multi-Criteria Approach for determining optimum evacuation routes using mobile phone data. This method uses mobile phone location data to determine routes. This approach seeks to minimize distance and congestion, while maximizing coverage for evacuees. In Chapter 4, I introduce a model for measuring risk to citizens and emergency responders during no-notice emergencies using social media data. This risk model enables first responders to identify threat areas and inform vulnerable citizens in those areas of the appropriate actions to take (e.g. shelter in place). Finally, Chapter 5 provides an overview of the contributions of this research and provides recommendations for future research.

Chapter 2: No-Notice Urban Evacuations: Using Crowd-sourced Mobile Data to Minimize Risk[1]

2.1 Abstract

Emergency evacuations during the past decade have transitioned from landline analog to mobile digital communication devices. Over 88 percent of U.S. citizens own a mobile phone, providing a tool to enable better communication between first responders and citizens in order to minimize risk to evacuees during no-notice evacuations. During an emergency, evacuees rely on social media to communicate with family, friends and coworkers, often finding accessibility to social media more reliable than trying to make a phone call. Federal, state, and local emergency operations centers have made limited use of social media or Internet based communications to provide an alternative means for citizens to request assistance or provide information. Mobile devices provide an alternative method of incident reporting and analysis through volunteered geographic information (VGI), which first responders can use to minimize risk to evacuees.

2.2 Introduction

On September 11, 2001, America was traumatized by the terrorist attacks at the World Trade Center in New York City, the Pentagon in Washington, DC, and the crash of United Flight 93 in Shanksville, Pennsylvania. Thousands of Americans and over 370 foreign citizens perished from the attacks and over one million evacuated from Manhattan (Kean, 2004; Anonymous, 2012; De Wind, 2012). Since then major attacks have occurred in other

[1]The majority of the material included in this chapter was submitted as a manuscript to Geography Compass: Oxendine C, and Waters N. 2013(in Review). "No-Notice Urban Evacuations: Using Crowd-sourced Mobile Data to Minimize Risk"

metropolitan areas around the world, including Madrid in 2004, London in 2005, Mumbai in 2006 and 2008, and Karachi in 2007. During large-scale terrorist events no-notice emergency evacuations usually occur in an unorganized fashion. Individuals near the periphery of terrorist events desire to find the quickest and safest route to their home or somewhere they will feel safe. 28 percent of evacuees from the World Trade Center didnt know where to go, and 12.9 percent reported that they didnt know how to get to their destination (Zimmerman and Sherman, 2011). These individuals rely on their knowledge of the surrounding area and public reporting through news media, emergency services, and social media to inform them of the hazards they may face in the area. Deciding to evacuate and choosing the wrong route to travel to their home or another safe destination can place them at increased risk.

Evacuees typically rely on prior knowledge of the area or use a mobile phone with assisted GPS or an Internet mapping service (e.g. Apple or Google maps) to find directions to their final destination. The resulting directions provide them with the shortest or quickest route; however, these directions often fail to account for the risk they may encounter along the route. Former U.S. Homeland Security Secretary Michael Chertoff's comments to students and faculty at George Washington University emphasized the importance of understanding and living with risk:

> "We must manage risk at the homeland security level. That means developing plans and allocating resources in a way that balances security and freedom when calculating risks and implementing protections. The most effective way, I believe, to apply this risk-based approach is by using the trio of threat, vulnerability and consequence as a general model for assessing risk and deciding on the protective measures we undertake." (U.S. Department of Homeland Security, 2005)

His comments emphasize the importance of increased awareness to the risk posed by terrorist attacks. British Prime Minister David Cameron called for a multifaceted approach instead of just militarily. . . including bringing together and forming great networks and alliances (Johnston, 2012). Citizens in close proximity to a terrorist attack are aware of the increased risk they face; however, they have no means of determining how to minimize risk as they negotiate a way through an evacuation zone. During recent disasters and terrorist attacks, citizens have used their mobile devices to access social media platforms such as Twitter, Flickr, and Facebook to share information with friends, family and others (Wallop, 2011; Crowe, 2012; Meier, 2012b). Social media provide a rarely used source of data that can be harnessed during such events. Zook et al. (2010) found in Haiti that aggregating data, including SMS messages, maximized the benefits to relief personnel. Collecting and analyzing multiple sources of publicly available data and analyzing it to provide evacuees with an evacuation route is one method of minimizing risk to citizens and first responders during a terrorist attack.

Several challenges exist for emergency management personnel when a no-notice evacuation occurs including: determining what has happened, where it occurred, who is affected, how to mitigate the risk for evacuees and first responders and finally how to we communicate the risk and determine what actions to take. All of these challenges involve geographic information from multiple sources that emergency managers must rapidly be able to assess, coalesce and analyze. Then they must quickly decide the best course of action to minimize further loss of life and property.

Emergency managers are faced with providing direction to citizens on whether they should evacuate, where the evacuation shelters are, and what is the safest and quickest route? Limited information about what exactly occurred and where it occurred often slows the release of information from emergency managers to the public. Providing sufficient information on the impact to specific geographic areas and populations increases the likelihood that citizens will appropriately respond to directions from emergency managers (Glik, 2007). Galloway (2003) highlights several important lessons learned from the attacks on the World Trade Center and Pentagon, including the importance of Geographic Information Systems (GIS), Decision Support Systems, and Public Communication. Galloway emphasized the importance of GIS products in New York City to communicate with the public about risks and where to find available resources (evacuation zones, hazardous areas, shelters and hospitals). Geographic information systems provide a toolset that enables emergency managers to model risk and make more informed decisions about which areas to evacuate as well as provide a mobile tool to evacuees to mitigate their risk during a no-notice evacuation. This research provides an overview of no-notice emergency evacuation procedures and introduces a new method for minimizing risk to evacuees and first responders during a no-notice evacuation.

2.3 Overview of Emergency Evacuations and GIS

Geospatial Information Systems (GIS) provide a tool for federal, state, and local government agencies to mitigate risk, and to prepare for, respond to and recover from man-made and natural disasters. Government officials must be aware of how to integrate GIS into their emergency management cycle. Research has found that GIS implementation in emergency management can fail due to a lack of available data and models, as well as a deficiency of knowledgeable GIS analysts (Zerger and Smith, 2003). If emergency managers are aware of the usefulness and ease of use of GIS tools, they are more likely to integrate geospatial tools into risk assessment, mitigation, preparedness, response, and recovery (Toomey et al., 2009). Kwan and Lee (2005)emphasize the importance of both the access to accurate, real-time data from numerous sources as well as the protection of large GIS databases from misuse by terrorist groups. Better methods are needed for visualizing risk, vulnerability and accuracy of the relevant spatial and temporal information (Cutter, 2003). One of the most challenging problems in no-notice evacuations is determining the population affected within an evacuation zone (Cova, 1999). As of 2011, there are over 5.9 billion mobile-cellular subscriptions worldwide, an increase of 45 percent since 2007 (International Telecommunications Union, 2011a). With increasing bandwidth and saturation rates of smartphones globally, as shown in Figure 2.1, GIS can be used through a mobile application to communicate and share knowledge with the public about an emergency (International Telecommunications Union, 2011a; Sui and Goodchild, 2011). In no-notice evacuations, GIS provides an effective tool to calculate incident risk, provide emergency managers with a common operational picture similar to that used by military commanders, and serve as a platform to share this knowledge with citizens and first responders.

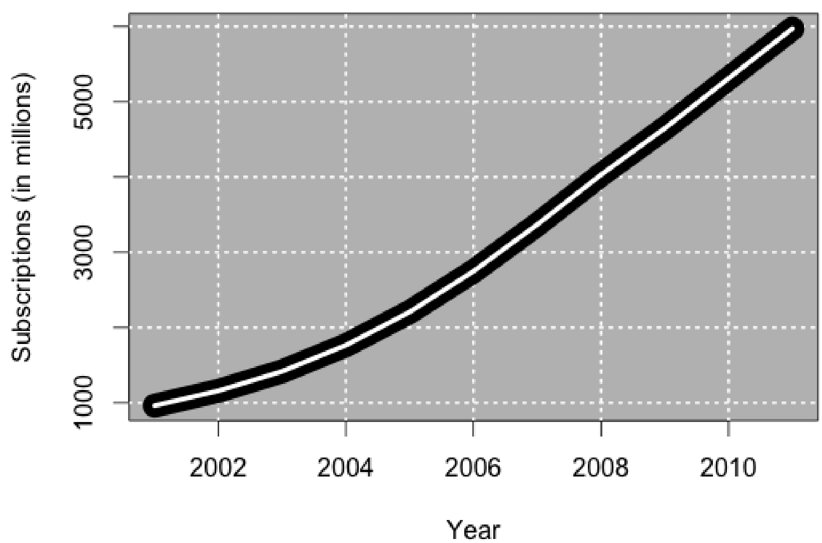

Figure 2.1: Worldwide Mobile Phone Subscriptions, 2001–2011 (Source: International Telecommunications Union, 2011a)

2.3.1 Challenges of No-Notice Evacuations

No-notice evacuations transpire when an incident, such as a terrorist attack, tsunami, tornado, or earthquake, occurs with limited to no warning (Zimmerman et al., 2007). Events range in scale from local to entire cities or regions of a country. Emergency response planning is usually entirely reactive because of limited planning. The size, location, nature of the incident and time of day are among the key factors affecting the complexity of no-notice evacuations (ibid). These factors impact how many people are affected by the evacuation and how quickly first responders can evacuate personnel.

Trust in warning messages is one of the most important factors for citizens in emergency evacuations (Glik, 2007; Paul, 2012). Glik also found along with trust, if citizens received detailed information about the severity of risk, they were more likely to evacuate in an orderly manner and respond to directions of emergency managers (Glik, 2007). Although rumors are spread using social media, Richards and Lewis (2011) found in the 2011 London Riot that rumors were often dispelled within two to three hours. Similar challenges exist with existing emergency reporting methods. For example, in 2011, police in Britain reported less than 25% of over 7.5 million calls were real emergencies (Boyle, 2012). In order to establishing trust in social media during emergencies, emergency managers and organizations should maintain a social media presence before events happen, thereby establishing credibility with other users prior to an emergency.

2.3.2 Communication During No-Notice Emergency Evacuations

Although providing information to the public has improved dramatically over the past 50 years, only limited research and applications have been introduced that improve two-way communication and additional methods of communication between citizens and emergency managers. Current methods of notification include: news, radio, social media, and, in the US, the Commercial Mobile Alert System (CMAS). Communication between emergency managers and the community is primarily through 911 call centers. Citizens receive information from numerous sources including news media, the Internet, social media, and recently through mobile phones. Currently, the only method of reporting an emergency situation in the US is to call 911 or the local number for your 911-call center. Past incidents have illustrated the importance of multiple lines of communication (Federal Communications Commission, 2006; Callahan, 2012); however, policies and procedures have not been established to provide alternative methods of communication with 911 call centers such as using newer technologies including the Internet, Skype, or even social media.

Some federal, state, and local agencies have made efforts to share information on the Internet and social media (Twitter and Flickr); however, limited efforts have been made to use the Internet and social media as a two-way communication platform (Latonero and Shklovski, 2011; Wallop, 2011; Meier, 2012b). The 2010 Haiti earthquake was the first effort by the U.S. Government to rely on social media to coordinate efforts among various federal agencies (Yates and Paquette, 2011). On June 29, 2012, over 2.3 million residents in Northern Virginia understood the importance of multi-modal communications when 911 services where lost following a Derecho storm, with full service restored over 4 days later (Flaherty, 2012).

The U.S. Federal Emergency Management Agency (FEMA), in coordination with the Federal Communications Commission developed CMAS, re-named Wireless Emergency Alerts (WEA) in February 2013 (Federal Communications Commission, 2013). WEA sends geographically targeted alerts to citizens to notify them of hazards they may be exposed to based on their mobile phone location Federal Emergency Management Agency (FEMA, 2012b). WEA is a complement to television, radio, Internet and other notification services; however, several challenges exist with WEA. WEA is a one-way communication platform that prevents citizens from providing information about hazards or from requesting emergency services. In addition, WEA only allows up to 90 characters to be transmitted in its alerts, limiting the message content to type of event, time alert expires, and recommended action Federal Emergency Management Agency (FEMA, 2012b). FEMA states that one-way communication is used in order to protect the privacy of citizens; however, it is also a shortcoming of WEA. When a citizen requests assistance through a 911-call center, they must provide a location in order to receive assistance. Developing procedures to allow citizens to volunteer their location (Volunteered Geographic Information or VGI) provides a measure of security and an alternate method for citizens to request emergency services when they cannot reach a 911 operator.

2.3.3 Mobile Phone Use in Emergency Evacuations

Mobile phones should not be regarded as a primary or sole-source communications device. They supplement other existing communication sources such as analog phones, television, radio, and social media. Smartphones provide multiple modes of communicating including phone, Short Message Service (SMS, also known as text messaging), Internet, and social media.

In 2011, the Pew Research Center found over 40 percent of mobile phone owners used their mobile phone during an emergency (Pew Research Center, 2011). As of March 2012, over 88 percent of Americans own a mobile phone and more than 46 percent of Americans own a smartphone (Pew Research Center, 2012). Over 50 percent of Citizens in Australia, the United Kingdom, Sweden, Norway, Saudi Arabia, and United Arab Emirates own a smartphone and over 40 percent own a smartphone in New Zealand, Denmark, Ireland, Netherlands, Spain, and Switzerland (Pham, 2012). With increasing numbers of citizens using GPS enabled smartphones, emergency management should evaluate how they can integrate newer technologies into 911 call centers as well as how these technologies can better support response by first responders.

Positional accuracies of mobile devices vary depending on whether the device is GPS enabled and activated, and on whether an individual shares their location as a coordinate such as latitude and longitude or a description of their location (e.g. $34.2345, 58.8989$ or New York City, NY). Although accuracies fluctuate, studies on cellular phone position data have found up to 50-meter accuracy rates using 30-second updates (Cayford and Johnson, 2003). Current models of phones have the ability to send GPS collected locations, although not all users provide location data with their GPS enabled phones. More recent research on GPS-assisted phones found average accuracies of 8 meters (Zandbergen, 2009). This will be addressed below as part of the research that is described for the modeling of risk within the city.

Frank et al. (2004) emphasize the importance of mobile GIS solutions and cellphone sensors for fire fighters, field workers and tourists. Mobile phones provide several opportunities to improve two-way communication between citizens and emergency management personnel. First, they provide a means for sharing information through social networks, such as Twitter and Flickr among others. Second, aggregated mobile phone location data could also be used to estimate diurnal population change in urban settings to determine how many people are impacted by an event and what resources are needed during the response. Third, mobile phones provide the ability to send low bandwidth text messages to 911 call centers; however, the ability and procedures to capture and respond to text messages in 911 call centers do not yet exist. Finally, in the US smart phones provide FEMA with the ability to deliver an all-in-one mobile application to citizens. This type of mobile application should incorporate many features including: shelter in place procedures, basic first aid, and the ability to download and save to the users phone local maps and phone numbers of the evacuees local 911 call center, fire, EMS and police services.

2.4 Mitigating Risk While Protecting Individual Privacy

Mobile phones can provide a wealth of information to support no-notice emergency evacuations, however, government officials must also be cognizant of protecting the privacy of its citizens. Modern computer technologies continue improving our ability to process larger datasets and more challenging problems, including the use of individual location data during an emergency. Mobile applications have been developed that are tailored to a users current location and provide a means to track an individuals movements, although few individuals are comfortable sharing their location at all times (Gruteser and Liu, 2004). During an emergency, citizens expect to be protected by government agencies but they also expect to maintain a certain level of anonymity. Implementing a GIS to facilitate emergency response using an individuals mobile phone location poses the question: how do we provide assistance to citizens while also protecting their privacy (Li and Goodchild, 2010)?

The World Economic Forum (WEC) recently published a report on the challenges of personal data citing a lack of globally accepted policies and procedures that protect the privacy of individuals (World Economic Forum, 2011). Research by Kwan et al. (2004) emphasizes the importance of the use of geo-referenced, individual data but also the protection of personal privacy. Kwan et al. evaluate the use of three types of geographical masks for protecting the privacy of citizens: aggregation, affine transformations, and random perturbations and found that increasing accuracy of the original data (a desirable quality) increases the risk of disclosure. Examples of protecting personal privacy during emergencies for each of these masks are provided in the following:

- **Aggregation** - Mobile phone location data is aggregated to the nearest intersection in a city or grouped according to census tract or city block

- **Affine Transformation** - Mobile phone locations are shifted a certain distance and direction from actual location

- **Random Perturbations** - Random errors are introduced into the mobile phone locations. For example, a random point is chosen within 500 meters of the original location to represent the correct point.

In the realm of emergency evacuations, further analysis is needed to determine an optimum solution to protect the privacy of citizens while also providing them with the optimum evacuation route that minimizes risk and distance traveled. There are a lack of guidelines on when it is appropriate to collect information from individuals without their knowledge while maintaining their privacy (Sui and Goodchild, 2011). With increasing concerns over spatial data privacy, Elwood and Leszczynski (2011) states that the current privacy conflicts will influence expectations of citizens and policies and procedures that data stakeholders follow. In a recent survey, Kar et al. (2013) found that the majority of U.S. citizens agreed to the collection of location data during an emergency; however, there was disagreement over how how the location data could be used.

In conjunction with state, local, and tribal emergency managers, FEMA should evaluate and implement better methods of integrating mobile devices and social media into emergency response while providing a solid measure of privacy for citizens. To alleviate concerns of citizens regarding location privacy during an emergency evacuation, location data should only be shared when an individual authorizes this data to be shared or when they send location data directly to emergency managers. Placing the location sharing 'on/off' button where a message is sent would enable citizens more control over when their location is shared or not. As with a 911 call, if procedures are put in place to capture emergency reports through the Internet or social media outlets, then location data should be sent automatically to 911 call centers using secure Internet protocols. Other concerns such as language translation should also be addressed while determining the appropriate procedures to process the messages. This ensures that when an emergency is reported first responders will have the ability to respond to an incident as needed.

2.4.1 Social Media and Emergency Evacuations

Emergency managers are beginning to understand the wealth of information that social media can provide and are working to develop procedures for collecting reports from social media. Understanding relationships and interactions within social networks provides an opportunity to gather and analyze valuable information leading to additional insight during emergency response (Li and Goodchild, 2010). Many emergency managers around the world realized the importance of smartphones and Twitter after the 2011 earthquake and tsunami in Fukishima, Japan. In September 2012, the Japanese government conducted an exercise in coordination with Twitter to send initial quake alerts and evacuation routes. In turn, citizens were expected to report injured people along evacuation routes (Russell, 2012). In the United States, several state and local governments used an Ushahidi crowdmap during Hurricane Sandy (Waters, 2011). Twitter hashtags could be used to report power outages, downed trees, or other hazards. Ushahidi, established in 2008, was initially used following the Haiti earthquake in 2008 to collect VGI from users through SMS, MMS (Multimedia Messaging Service), and the internet (Okolloh, 2009; Meier and Munro, 2010; Zook et al., 2010). This information was shared with emergency response and relief workers which enabled them to determine how to employ their limited resources efficiently (Okolloh, 2009). Efforts to integrate social media into emergency responses have improved. Additional efforts to optimize the integration of social media during emergencies could include the development of: (1) methods to geo-fence social media data based on 911 call center jurisdictions, (2) procedures to use social media as an alternate two-way communication method, (3) emergency hashtags which are always geolocated and (4) a process to educate the public on the appropriate use of these hashtags.

As of 2012, social media is mainly used as a one-way communication tool. Social media is not a primary means of communication. However, social media can be used as an alternative method for two-way communication between citizens and emergency management. Social media provides an ad-hoc platform for connecting individuals with different experience levels and enabling a flexible, yet robust method for gathering, sharing, and employing knowledge for emergency response (Yates and Paquette, 2011). A social network dedicated to emergencies would be an accepted tool, especially among younger citizens (White et al., 2009). Teen mobile phones rates have increased from 45 percent in 2004 to 77 percent in 2011 (Lenhart et al., 2010). Figure 2.2 provides a recent analysis of mobile phone rates across individual generations. Since Ages 12-17 data was not collected for 2010, 2011 data was used for Ages 12-17. Brenner (2013) found that 67% of online adults in the U.S. use social networking sites. 71% of women use social media compared to 62% of men and that 70% of urban citizens use social media compared to 61% in rural areas.. In Figure 2.3, younger generations use social media more than older generations. As emergency managers realize the increasing value of mobile phones and social media as a situational awareness tool, additional efforts should be made to integrate efficiently these tools into the emergency management cycle via a common methodology and application.

The phrase given enough eyeballs, all bugs are shallow is known as Linus Law (Raymond 2008). The so-called Linus law can be applied to the collection and analysis of VGI during emergency evacuations and terrorist events in densely populated areas. For example, in a densely populated city like New York City or Washington, D.C., the majority of citizens use a smart phone and most smartphones are GPS enabled. Zickuhr (2012) found that 74% of smartphone owners use real-time location-based services on their phone. With a

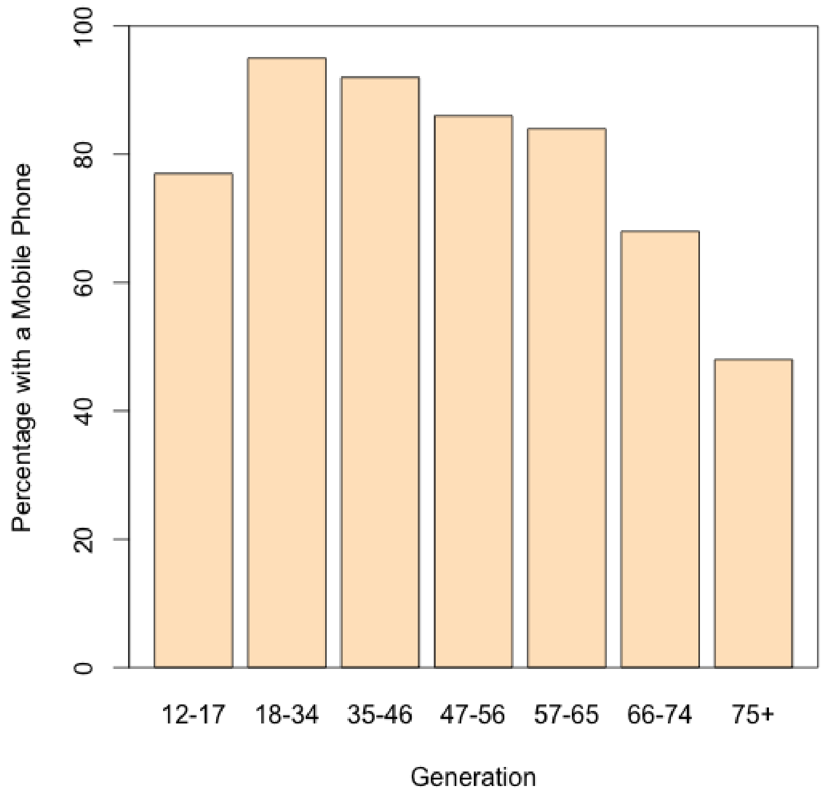

Figure 2.2: Percentage of Americans in 2010 who own a Mobile Phone, by Generation. (Source: Lenhart et al., 2010; Zickuhr, 2011)

population of over 8 million people, NYC provides an excellent opportunity to use VGI to report emergency events (e.g. a car bomb, or a shooting and hostage situation at a school, etc.) (New York City Population Division, 2010). VGI, about the location and type of event, as well as photographs, could be used by emergency services and citizens to minimize their risk in the hazard zone.

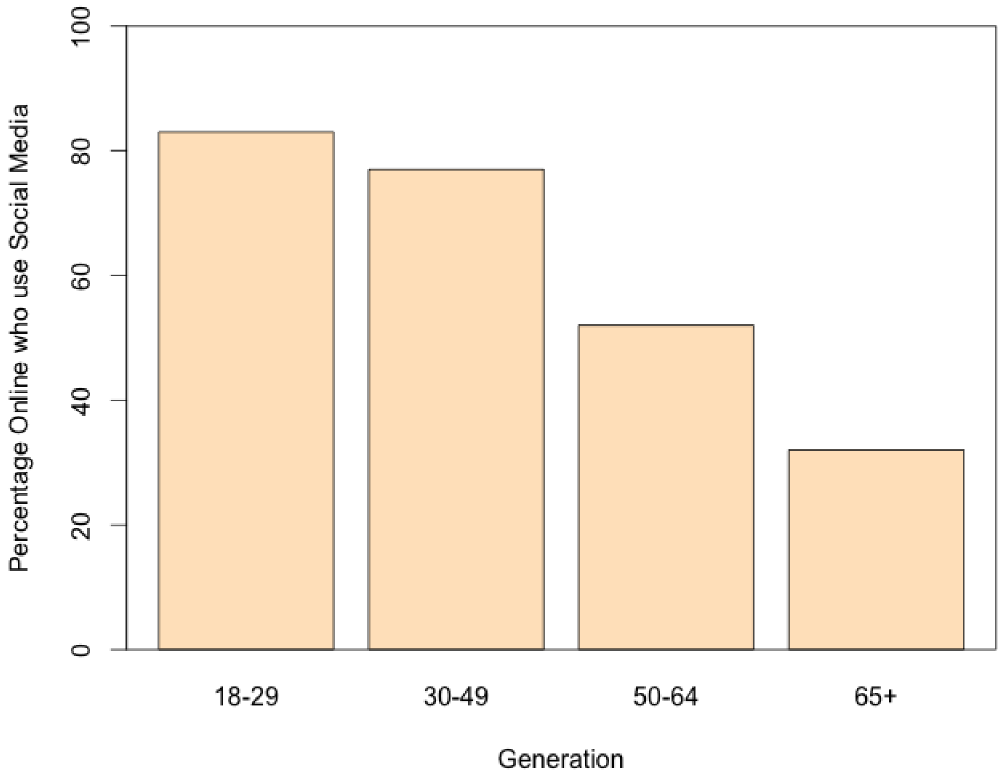

Figure 2.3: Percentage of Online Americans in 2012 who use Social Media, by Generation. (Source: Brenner, 2013)

2.4.2 Minimizing Risk with VGI

Data fusion supports the collection, organizing, and interpreting of multiple sources of data during an emergency evacuation. Using GIS to analyze the data during an emergency evacuation assists planners and decision makers during the mitigation, preparation, response, and recovery (Cova, 1999; Toomey et al., 2009). During a no-notice evacuation, emergency services personnel utilize response plans or standard operating procedures to respond to events.

Traditionally, citizens have relied on knowledge of the surrounding area, emergency services personnel, and their social networks (including family, friends, and colleagues) to evacuate from the hazard zone. With increasing use of social media to share information, many citizens now disseminate information and expect to receive information through social media (e.g. Twitter, Facebook, etc.) (American Red Cross, 2011b). Social media sites allow individuals to connect to personal and professional networks (Crowe, 2012). For example, an individual may have a personal account on Facebook to stay connected with family and friends; however, their account on LinkedIn is for professional connections. A sense of trust is developed by followers and stakeholders when they belong to a social network over time; therefore, developing a method of utilizing social networks prior to an event is critical to ensuring trust between government agencies and citizens (Crowe, 2012; Waters, 2013). In a 2011 survey, 80 percent of the general population believed that social media sites should be regularly monitored by national emergency response organizations (American Red Cross, 2011b). The Risk Steering Committee of the U.S. Department of Homeland Securitys Office of Risk Management and Analysis found that outside of natural disaster preparedness, DHS risk capabilities and methods are not yet adequate for supporting DHS decision making, because their validity and reliability are untested (National Research Council, 2010). The Australian Government evaluated social media as a tool for collecting and sharing information during emergencies and seeks to use this real-time crowd-sourced information to help people make the right decisions in a more timely manner (NGIS, 2009).

Using VGI is an important resource to further develop, thus enabling citizens to become sensors (Leslie and Waters, 2009). Social media has proven effective in modeling and visualizing the effects of disasters and other events across geographic areas (Stefanidis et al., 2011). Cheng et al. (2010) found that 5% of Twitter users had detailed location data (e.g. coordinates) and about 21% had a local granularity (e.g. city, borough) whereas Stefanidis et al. (2011) found that 16% of Twitter users had detailed location data and 45% had a local granularity. Most recently, Crooks et al. (2013) found 14.7% of tweets with detailed location data; however, about half of those were retweets. Differences in the percentages of detailed location data may be accounted for by differences in the percentage of smartphone devices as well as cultural sensitivity to sharing location data.

Crowdsourcing and harvesting geographic information has proven to be more beneficial to emergency response personnel than the risks associated with using this data (Goodchild and Glennon, 2010; Stefanidis et al., 2011). Using VGI and Ambient Geographic Information (AGI) provides additional information (although with some level of uncertainty) and therefore these data can be used to determine risk within the evacuation zone during no-notice evacuations. This research (Oxendine et al., 2012) seeks to provide a model for minimizing risk and distance traveled for evacuees during a no-notice evacuation scenario in a major metropolitan area by including VGI and AGI along with emergency services reports (evacuation zones, incidents, among others).

The US Department of Homeland Security model for risk analysis is a function of threat (t), vulnerability (v), and consequence (c) (National Research Council, 2010). Models have been developed that accurately model risk for natural disaster preparedness. However, the task force did not find any evidence that other areas within the DHS model were accurately represented. Our future research efforts seek to address risk in urban environments by modifying the current DHS risk model. Goodchild and others have addressed the concerns of accurate reporting when using VGI and AGI (Goodchild, 2007a; Goodchild and Glennon, 2010; Haklay, 2010; Li and Goodchild, 2010) . In the Santa Barbara fires, Goodchild and Glennon (2010) found that the need for timely information was more important than the concern over the quality of the data received. This research seeks to address the need for a model that provides timely information, using VGI and AGI, while also providing a measure of confidence in the accuracy of the model.

VGI, introduced by Goodchild (2007a), refers to the information that volunteers collect and submit, for example to open source mapping projects. Open source mapping projects are successful because individuals volunteer their time to collect, submit, and edit information on the maps. There were over seven billion people on our planet, each capable of collecting and sharing volunteering geographic information about their location (The World Bank, 2012; Goodchild, 2007a). Mobile devices provide a platform for collecting VGI and provides two-way communication in the form of text messages, voice messages, and mobile applications. Current remote sensing technologies lack the fidelity of billions of mobile sensors provide to geographers, emergency personnel, academics, and others.

The impacts of VGI on mapping provide tremendous potential to impact billions of citizens around the world. Although there are still questions, about the quality of VGI data, as noted above given enough eyeballs, all bugs are shallow (Raymond, 2008), and entities such as OpenStreetMap provide accurate maps using the idea that when many people scan and cross reference their maps they will find and correct discrepancies. This is known as The Wisdom of the Crowds (Surowiecki, 2004) or more recently crowdsourcing (Howe, 2006; Sui et al., 2012). There is not universal agreement on the definition of crowdsourcing (Estellés-Arolas and González-Ladrón-de Guevara, 2012). Estellés-Arolas and González-Ladrón-de-Guevara review the literature on crowdsourcing and define any type of crowdsourcing as "a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task." For example, for OpenStreetMap that task has been the creation of a reliable road network.

Harvey (2013) divides crowdsourced geographic information into volunteered geographic information (VGI), where a user opts-in and contributed geographic information (CGI) where the user opts-out. An example of VGI is the submission of GPS and attribute data to update OpenStreetMap, whereas an example of CGI is the collection of location and speed data from mobile phones to detect traffic patterns on highways. Whether a contributor opts-in or opts out affects when and how the data can be visualized, shared, or translated (ibid.). The importance of contributors of VGI or CGI to an understanding of when and how the data they are contributing is used highlights the privacy concerns, noted above, that citizens may have with the use of their data during an emergency evacuation.

Evacuation route optimization has been researched for many years leading to improvements in emergency evacuations routing (ReVelle and Swain, 1970; Church and Cova, 2000;

Kwan and Lee, 2005; Alçada-Almeida et al., 2009; Oxendine et al., 2012). Altay and Green (2006) propose that operations research has significant applications during disaster response and call for improved methods and technology to improve disaster management. Abdelgawad and Abdulhai (2009) outline two important challenges in determining routes during emergency evacuations: a lack of hazard prediction methods that model the predicted hazard area and a lack of methods for dynamically assigning evacuation routes within the network. Integrating VGI, such as citizen locations and reported incidents (e.g. Waze), into previous models enables emergency managers and citizens to model risk in an evacuation zone. VGI also enhances the ability of emergency managers to route citizens on evacuation routes while minimizing risk and distance traveled. Smartphones, social media, and mobile mapping applications provide a toolset that enable two-way communication between citizens and government officials and address the challenge of dynamically routing citizens during a no-notice evacuation.

2.5 Conclusion

Methods for leveraging evacuee locations and providing notification and evacuation routes in an evacuation zone cross into a new paradigm with the availability of smart phones and increasing positional accuracy. The following elements must be implemented to successfully develop a mobile application platform that supports no-notice emergency evacuations: education of the public, optimization of evacuation routes, development of methods of two-way communication and a common platform for citizens and government officials.

Education of the public on how mobile applications support emergency evacuations and how their privacy is protected is key to building trust in the common platform. As part of this effort, FEMA and other emergency management organizations must continue their efforts to educate citizens on the proper procedures for using mobile devices, mobile applications, and social media during an emergency. Efforts to educate citizens on tools available during a crisis should occur continually; however, many citizens are likely to search for assistance or information just before or after an event. Increased marketing during these times would most likely have the biggest benefit for citizens and emergency agencies.

Researchers have called for additional methods for fusing GIS and social media (Sui and Goodchild, 2011). GIS-supported mobile applications and social media provide alternative methods of two-way communication that allow citizens to report incidents to a 911-call center. Using GIS to analyze information reported through mobile applications and social media during a no-notice emergency evacuation enables government officials to model risk and communicate this risk to citizens through various communication modes. As was seen in past incidents, 911 operations centers lose communications through analog phones and methods must be established to provide alternative and contingency communication methods. The ability to connect through cellular or Internet networks as an alternative communication method is necessary. Mobile technologies are continuously improving and provide an increased ability to emergency managers to augment risk awareness among citizens and therefore mitigate hazards during evacuations.

For the duration of Hurricane Sandy, Federal, State, and Local agencies as well as corporate entities made Internet and mobile applications available for reporting incidents. Yet with so many options available, there was limited collaboration across the mobile applications. Although a step in the right direction, there is a need for a common platform developed in coordination with international, national and local government agencies that enables citizens to communicate with emergency managers and for government agencies to share information. This common platform should provide a spatially and temporally integrated capability for the emergency operations center to receive and analyze reports from citizens within their jurisdiction.

As noted above, the Japanese Government recently conducted an emergency exercise in coordination with Twitter (Russell, 2012). Twitter and smartphones were keys tools used by the Japanese Government for emergency notification and sharing information with its citizens. The next step in improving these systems is enabling two-way communication and improving accessibility of maps during an emergency, thus providing citizens with an alternative communication method and mapping tool. Not only would citizens benefit, but non-government and government agencies would benefit from a common platform that could assist in identifying impacted areas and focusing response efforts in those regions (Oxendine et al., 2012). As part of this effort, citizens should be educated on alternative methods of communicating risk during an evacuation resulting in increased awareness to their community and emergency managers during the next disaster. Emergency managers would also be more knowledgeable of the risk to citizens and be better prepared to communicate this risk through multiple communication channels. With the capabilities of collecting data, analyzing it, and sharing visual and textual information, geographic information systems are ideally positioned to provide and coordinate these developments.

Chapter 3: A Multi-Objective, Multi-Criteria Approach to Improve Situational Awareness in Emergency Evacuation Routing Using Mobile Phone Data[1]

3.1 Abstract

Emergency services personnel face risks and uncertainty as they respond to natural and anthropogenic events. Their primary goal is to minimize the loss of life and property, especially in neighborhoods with high population densities, where response time is of great importance. In recent years, mobile phones have become a primary communication device during emergencies. The portability of cell phones and ease of information storage and dissemination has enabled effective implementation of cell phones by first responders and one of the most viable means of communication with the population. Using cellular location data during evacuation planning and response also provides increased awareness to emergency personnel. This chapter introduces a multi-objective, multi-criteria approach to determining optimum evacuation routes in an urban setting. The first objective is to calculate evacuation routes for individual cell phone locations, minimizing the time it would take for a sample population to evacuate to designated safe zones based on both distance and congestion criteria. The second objective is to maximize coverage of individual cell phone locations, using the criteria of underlying geographic features, distance and congestion. In summary, this paper presents a network-based methodology for providing additional analytic support to emergency services personnel for evacuation planning.

[1]The majority of the material included in this chapter was submitted as a manuscript to Transactions in GIS: Oxendine C, Sonwalkar M, and Waters N. 2012. A Multi-Objective, Multi-Criteria Approach to Improve Situational Awares in Emergency Evacuation Routing Using Mobile Phone Data. 16(3):375-396.

3.2 Introduction

Natural and anthropogenic events that require emergency response and evacuation planning should have population dynamics as its cornerstone. First responders, not only have to safely evacuate the population to the safe zones, but also must pay special attention to children, elderly people, and disabled people. Evacuations based on objectives relevant to the response area are critical. Some of the objectives of a typical evacuation plan involve subjective priorities, time, communication, and maximal areal coverage. First responders plan and prepare for evacuations and assign resources based on defined objectives. Several challenges exist that could hamper an effective evacuation plan regardless of the location of the disaster and technological know-how of emergency response units. Disasters strike developed and developing regions as well as urban or rural communities. Effective means must be deployed across a particular region with adequate planning and foresight. However, the challenges are markedly different in the regional categories mentioned above.

This chapter discusses disaster response and evacuation planning for the borough of Manhattan, New York City, NY (see Figure 3.1). The challenges of achieving evacuation planning objectives for any densely populated city stem from three critical behavioral issues: 1) Altruistic behavior, 2) Normalcy bias and 3) Collective Syncing (National Research Council, Committee on Disaster Research in the Social Sciences: Future Challenges and Opportunities, 2006).

Altruistic behavior refers to a sense of concern for the welfare of others. This sense of helpfulness, although a noble virtue, could lead to a potential loss of life during emergencies. Normalcy bias refers to the mental state of human beings to underestimate the risks, during disaster, and its effects immediately after the disaster. This may lead to complacency on the part of individuals during emergencies and could lead to a breakdown of communication with the first responders. This of course, with the caveat that an orderly evacuation was not communicated to these individuals. The issue of collective syncing arises when individuals tend to follow each other as a group during disasters. This could also lead to a potentially disastrous situation when group leadership makes a wrong decision, especially when time

Figure 3.1: Map of the Study Area

is critical. As emergency personnel prepare and plan for evacuations, ideally they should take into consideration these important factors.

Mark Weiser, one of the early researchers of ubiquitous computing, commented on the trend of pervasive computing across several problem domains (Weiser, 1991, 1993). The extension of these ideas across disaster response and recovery occurred as a direct result of this vision (Jiang et al., 2004; Catarci et al., 2008). In terms of providing users services, ubiquitous computing refers to the accessibility of communication and computation with individuals via handheld gadgets, such as cell phones and smart phones. In the case of disaster response, first responders will be better equipped with a service that can communicate with individual cellphones and therefore provide subjects with directions to guide them to safety. This first responder-subject communication via mobile phone is critical to avoid a host of issues related to evacuation planning, including the three behavioral issues listed above.

In June 2011, the United States mobile penetration rate was over 101% (CTIA - The Wireless Association, 2012). The International Telecommunications Union (ITU) estimates that there are currently over 5.9 billion mobile subscriptions around the world (International Telecommunications Union, 2011b). Leveraging technology as a component for ubiquitous communication and computing is only natural. Emergency response personnel are responsible for conducting emergency operations, including, but not limited to emergency evacuation and response. Performing spatial analysis for route calculations includes static and dynamic mapping in the emergency evacuations arena. Therefore, emergency planners require a set of analytics that can be quickly deployed and provide them with various evacuation options.

This chapter presents a methodology that can be adapted for use by emergency planners during their preparation for different emergency scenarios. The analysis uses the weights of evidence method and network route calculations to minimize time for individual evacuations and maximize coverage within the evacuation zone. Criteria used in the analysis includes: a) distance as a metric for time, b) congestion as a metric for time, c) spatial association of points with underlying geographic features as a metric for maximizing coverage, and d) area density as a metric for congestion for maximizing coverage.

The remainder of this chapter is organized as follows. Section 3.3 provides an overview of evacuation planning methods, including the use of geospatial techniques and network analysis to solve routing problems. Section 3.4 discusses the proposed methodology to plan an evacuation, using the weights of evidence method and network analysis. Finally, Section 3.4 presents results, followed by the conclusion and recommendations for future research.

3.3 Overview of Evacuation Planning Methods

Evacuation planning using route optimization has been extensively researched for several decades (ReVelle, 1989; Cova and Church, 1997; Church and Cova, 2000). The p-median problem, when studied in the context of evacuation planning, transforms a typical network based solution to a facility-network solution. If linear programming is used to solve a purely network based problem via route optimization, the facility-network problem can be solved using a combination of linear programming and/or spatial methods.

Revelle and Swain introduced a linear programming solution to the problem of central facility location (ReVelle and Swain, 1970). Revelle and Swains research provided a method for minimizing the travel time from numerous origins to their associated closest destination. GIS has been used to address the complexity of increasing the number of facilities and communities served to arrive at a computationally efficient solution (Church, 2002).

Over the years, evacuation planners have faced numerous challenges while determining how to efficiently evacuate people from an area and determine the best routes to evacuate individuals to safety (Cova and Church, 1997). Models have been developed to optimally locate emergency shelters for evacuations and for identifying evacuation routes in low-population urban areas by comparing day and night time routes for a changing population (Alçada-Almeida et al., 2009). One challenge that emergency evacuation planners face is diurnal population change or changes that occur as a result of a major event (i.e. sporting, music, etc). This causes population fluctuations yielding inaccurate evacuation planning procedures. Urban areas, in particular, are in a constant state of change and planners need decision support tools that provide them with accurate and updated information.

Some methods from operations research and computer science address efficient multi-objective, multi-criteria based solutions for resource management in supply chain and computer networks, which can be emulated for evacuation planning (ReVelle and Swain, 1970; Cova, 1999; Kwan and Lee, 2005). However, methods that can leverage evacuee locations and provide notification and evacuation route in an evacuation zone crosses into a new paradigm with the availability of smart phones and their positional accuracies. Cayford and Johnson (2003) have studied the use of cellular phone location data and associated accuracies. They found up to 50-meter accuracy using 30-second updates; however, accuracies are known to fluctuate (Cayford and Johnson, 2003).

3.4 Methodology

3.4.1 Weights of Evidence

The Weights of Evidence (Agterberg, 1992) method has been applied and customized with learning algorithms for studying spatial patterns of point features. It has a been used extensively in mineral exploration for identifying mineral deposits, given a host of geological layers as evidences for their predictions (Agterberg et al., 1993; Raines and Mihalasky, 2002). The method has also used to predict a hypothesis about occurrence of a phenomenon based on combining known explanatory variables (evidence) associated with the phenomenon. This paper applies weights calculations from the WoE method creating a spatial association matrix for use in the network route calculations and for the multi-criteria, multi-objective analysis for evacuation planning (as shown in Figure 3.2).

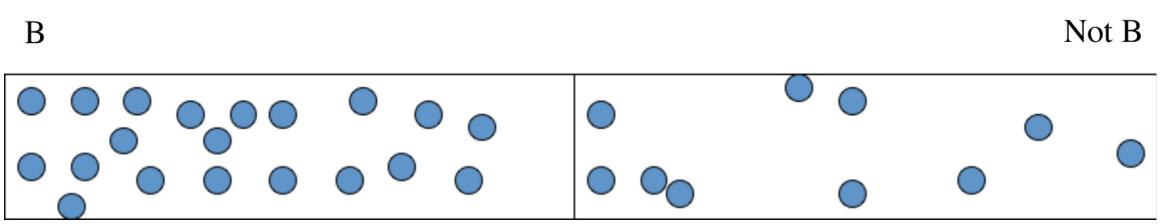

Figure 3.2: Illustration of the Calculation of Weights

The following demonstrates the weights calculations:

$N(T)$ represents the total number of unit cells across the B and $NOT\ B$ regions,

$N(B)$ represents the total number of unit cells covered by a category of geographic evidence B.

$N\ (D)$ represents the total number of cell phone locations in the evidence category.

$N\ (B\&D)$ represents an overlap between the cell phone locations and an evidence category.

Thus,

- $N(T) = 1000$ unit cells (total area (B + Not B))
- $N(B) = 500$ unit cells (Area covered by B)
- $N(B\&D) = 20$ (count of number of cell phone points on B)
- $N(D) = 30$ (count of total number of cell phone points)

The weights and Contrast C calculations are then represented as:

$$W+ = ln[P(B|D)/P(B|D)] = 0.2980 \tag{3.1}$$

$$W- = ln[P(B|D)/P(B|D)] = -0.4157 \tag{3.2}$$

$$C = W + -W- = 0.7138 \tag{3.3}$$

The conditional probability represented by $B — D$ seeks to find the probability of occurrence of a geographic feature given known cell phone locations. A complement $\complement$ to either (B or D) represents the absence of occurrence. In our example, there are two geographic feature (road connectivity towards safe zone, and proximity to the safe zone) themes - each with six categorical classes. Thus, there are 36 different weights calculation for the evidences. In the equations above, $W+$ refers to the weight associated with a categorical class of a theme, given the presence of subject (cellphone) D, whereas $W-$ refers to the negative weight and hence negative association with a categorical class of a theme, given the absence of subject (cellphone). The value of Contrast C, a measure of strength of association of each evidence layer towards the presence or absence of object is calculated by combining the higher positive weights with the higher negative weights (lesser in value). In simple terms, this scheme gives exaggerated preference to the presence of objects and penalizes the value of a particular evidence theme for their absence. C is used as a criterion weight for multi-objective / multi-criteria analysis. The studentized value of C, calculated as the ratio of C to its standard deviation, C/s ($S\_Contrast$), serves as a guide to the significance of the spatial association (Bonham-Carter, 1995).

3.4.2 Multi-Objective/Multi-Criteria Analysis

Decision rules are based on combination of subjective and objective information for the presented study. The decisions in our case involved choosing features for analysis and their classifications, choosing distance measures for safe zones, and choosing the appropriate generalization scheme. The data driven objective decisions were made by identifying the most relevant class categorization of features based on the known dataset and spatial association between various geographic layers. The following paragraphs defines the terms of objective and criterion and its descriptions for the presented study.

Objectives: The decision rules are identified based on the context of the objectives set for a particular problem. Objectives are means of testing the functional outcome of solving a problem analytically and can be used to validate the analysts intent.

Criterion: A criterion is some basis for a decision that can be measured and evaluated. Criteria can be of two kinds: factor and constraint. A factor is a criterion that enhances the suitability for an alternative, whereas a constraint limits the alternative under consideration.

For the presented study, the complementary objectives are to:

- Reduce time for individual evacuations and
- Expand coverage for evacuating most individuals.

To satisfy the above objectives, the following criteria was used for calculations:

- Distance as a metric for time
- Congestion as a metric for time
- Spatial association of points with underlying geographic features
- Area density as a metric for congestion.

The evacuation plan presented includes three safe zones locations. The buffer distance for these safe zones is 500 meters. The importance of evacuation beyond this buffer distance increases with the increased evacuation distance and time. Thus, given three safe zone locations, the task is to optimize routes from incident sites by minimizing distance and congestion, maximizing the spatial association with geographic features, and maximizing coverage to evacuees. A final optimization that will maximize the total score, which is a linear weighted combination of all the above factors is also desired. Table 3.1 shows the criteria for the two objectives.

Using weighted linear combination (Voogd, 1983), the criteria parameters are combined by applying scaled weights based on two parameters each, for weights of evidence and routes. Thus,

$$S = \sum w_i \, x_i \tag{3.4}$$

Table 3.1: Objective Criteria

Criteria	Minimize	Maximize	Factor	Constraint
Shortest Distance (Routes)	X			X
Road Congestion (Routes)	X			X
Spatial Association Geographic Features (WoE)		X	X	
Area Density (population coverage) (WoE)		X	X	

where, S is the suitability index, w_i is the weight of factor i and x_i is the criterion score of factor i. The criterion weights for the factors are computed using the WoE method, while the criterion weights for the constraints are computed using a cost function.

$$S = \sum C\, x_i \quad \text{for factors} \tag{3.5}$$

A contrast value C is calculated using weights of evidence method, providing both a positive and negative weight to the association between locations and the two chosen underlying geographic features (road connectivity towards safe zone, and proximity to the safe zone). The criterion weights for the constraints is based on a cost function:

$$S = \sum Cost_{ij}\, x_i \quad \text{for constraints} \tag{3.6}$$

Where, $Cost_{ij} = f(W, L, D)$. Here W represents the width of individual road segments, L is the length of individual road segments, and D is the shortest distance from the nearest safe zone.

After the factors and constraints are developed, evaluation of the criteria involves combining individual maps and ranking each of the cells to get an overall generalized evacuation map of the study area (see Figure 3.3). A test case for 11 sample cell phone locations are also evaluated for optimal routes to the safe zones using a linear weighted combination of the above four criteria as a cost along each of the routes (see Figure 3.4).

3.4.3 Network Routing

ESRI ArcGIS Network Analyst was used to determine routes for each of the criteria used in this study. The Network Analyst extension solves several routing problems, route analysis,

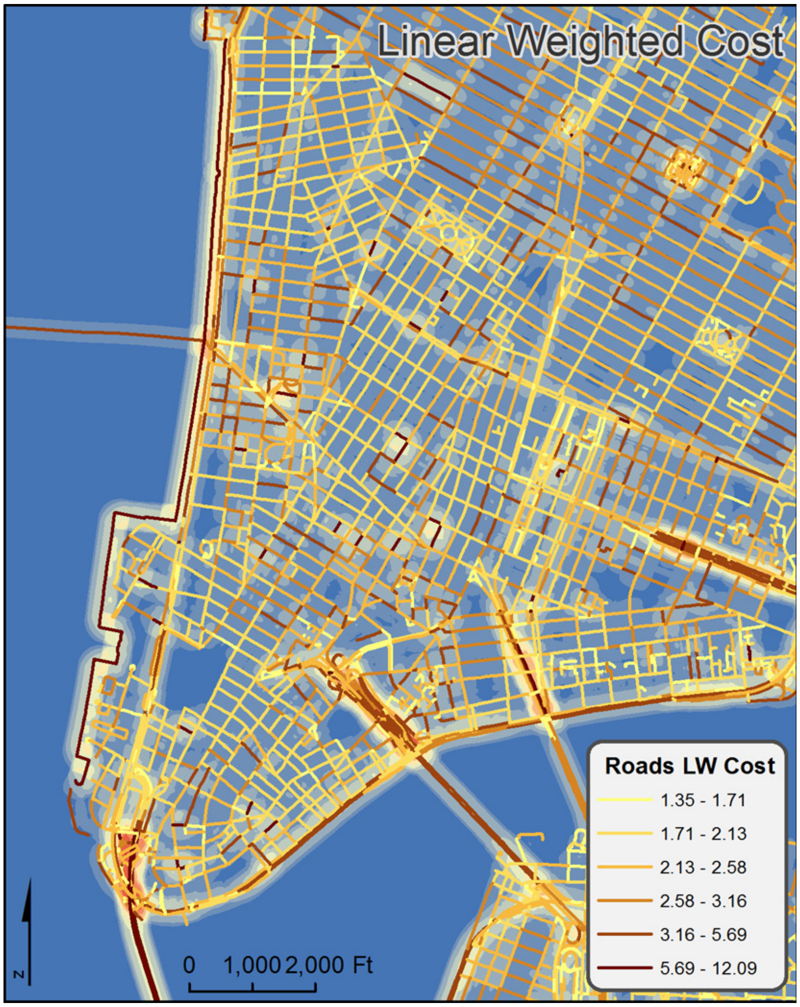

Figure 3.3: Linear Weighted Cost Map

closest facility, and Origin-Destination (OD) cost matrix. These tools are all based on Dijkstras Algorithm, a well-known algorithm that finds the shortest path on a graph (Dijkstra, 1959).

Route Analysis provides the shortest route from a starting point to one (or more) destinations in a network. Closest Facility determines routes from incidents and facilities, determining which facility is closer to each incident. Closest facility can solve for travel from the incident to the facility or from the facility to the incident. Closest facility determines the costs for traveling to the facility, as well as provides driving directions. Since

Figure 3.4: Best Routes Using Linear Weighted Cost

Closest Facility also provides driving directions, it is a less efficient method than the OD cost matrix. The OD cost matrix finds the shortest distance between multiple origins and destinations and is more efficient when solving for multiple origins and destinations. The closest facility tool provides the necessary information to complete our analysis of the routes, as well, as provide routing information from the incident to the Safe Zone.

The closest facility function is based on Dijkstras algorithm, which determines the shortest length between two nodes in a graph (Dijkstra, 1959). In Network Analyst, the shortest path between an incident and all facilities is determined and the closest facility is then

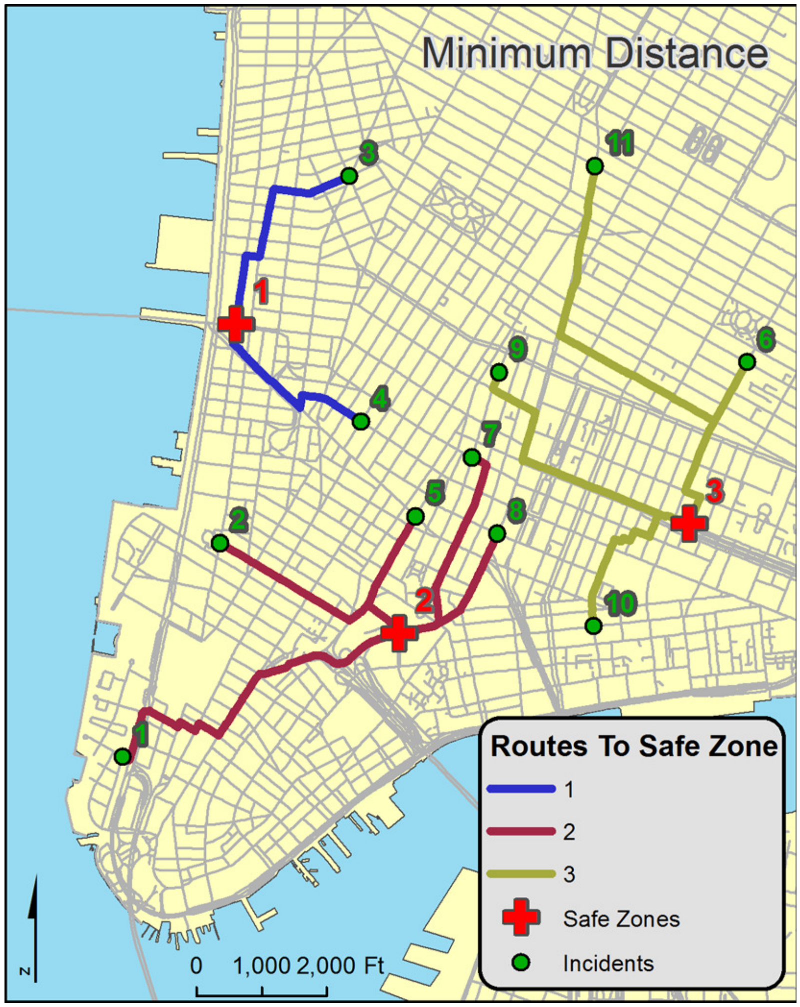

Figure 3.5: Shortest Routes

selected. Driving directions are provided from that incident to the facility.

The Closest Facility tool was used to find only one facility; however, it can be used to find more than one facility (i.e. to find the 3 closest facilities). There are additional constraints, such as limiting the route to a certain distance or time away from the incident. This can be used to limit the processing time or can be implemented as part of a real-world constraint. Finally, additional constraints such as adding point, line, or polygon barriers are very important when determining evacuation routes and ensuring evacuees are not directed into known hazardous areas.

Figure 3.6: Best Routes with Minimum Congestion

3.4.4 Determining Evacuation Routes

In order to determine the optimum route for individuals in the evacuation area, it is necessary to gather cell phone location data within the evacuation area, to determine designated safe zones, and to determine possible road networks and pedestrian trails that can be used as evacuation routes. The following section provides details on the determining the routes for each of the criteria and for the criteria combined.

The initial on-scene commander or the Emergency Operations Center (EOC) designates Emergency Evacuation Safe Zones. For this study, Designated Safe Zone #1 is located

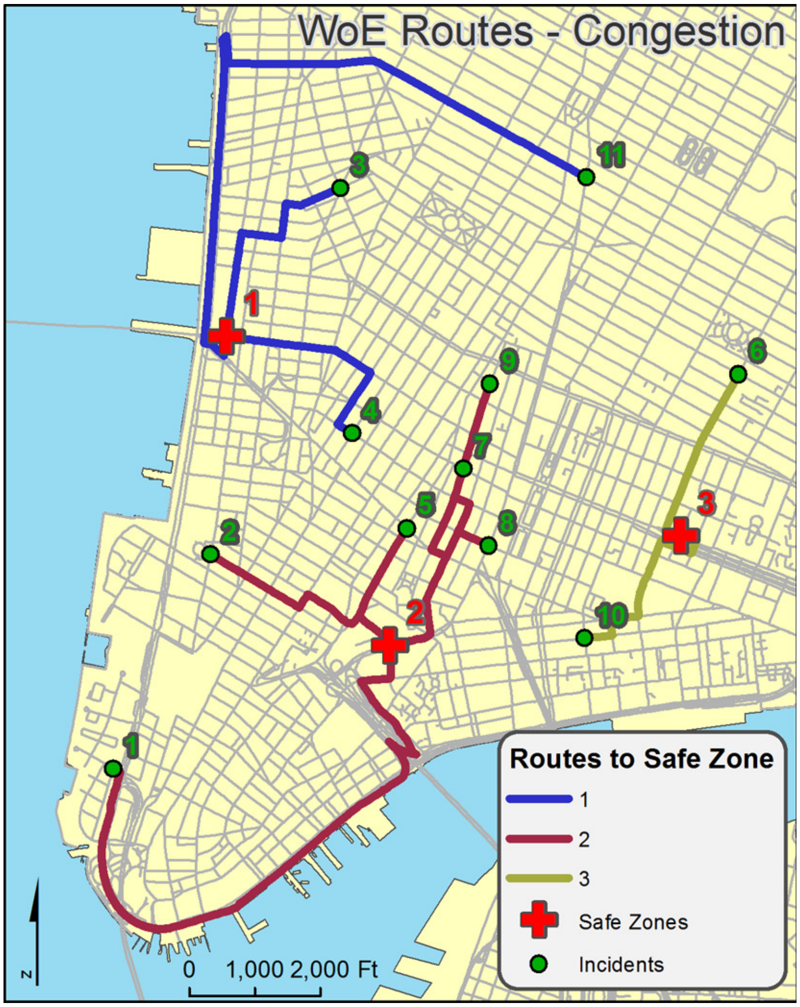

Figure 3.7: Best Routes Using Weights of Evidence to Minimize Congestion

at the parking lot of Public School 142 (intersection of Attorney St and Delancey St), which will be used as a staging area for emergency personnel as well as location for ground transportation to transport pedestrians away from the area. Designated Safe Zone #2 is located near a subway and hospital (intersection of Pearl Street and the Avenue of the Finest). Designated Safe Zone #3 is located in a large parking lot that provides a staging location for emergency personnel and ground transportation (intersection of Spring St and Washington St).

The on-scene commander or EOC designates the evacuation zone. To test the model for

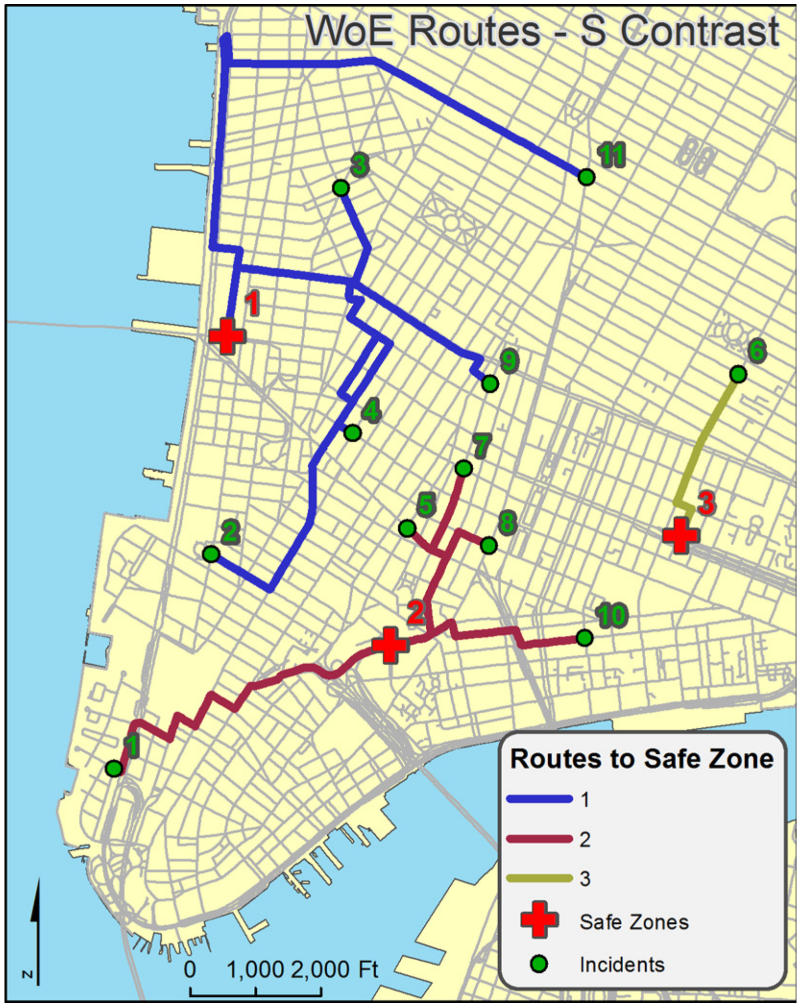

Figure 3.8: Best Routes Using Weights of Evidence - S_Contrast

determining the quickest evacuation routes, eleven (11) incident sites were randomly chosen in the study area. The first two criteria for determining the routes included: finding the shortest distance (Figure 3.5) and finding the route of least congestion (Figure 3.6) using the closest facility tool in ArcGIS Network Analyst. The next four methods used Weights of Evidence to determine the quickest evacuation routes: road distance minimizing congestion (Figure 3.7), road distance minimizing S Contrast (See Figure 3.8), shortest distance from the Safe Zones minimizing congestion (Figure 3.9), and shortest distance from the Safe Zones minimizing S Contrast (Figure 3.10). Finally, Figure 3.3 presents a linear weighted

Figure 3.9: Best Routes WoE Distance & Congestion

combination to solve for the best route from each incident to their closest Safe Zone. Routes for each method were solved using ArcGIS Network Analyst after determining the cost of the road arcs. An overview of this methodology is provided in Figure 3.11.

The next step is to determine optimum routes from each evacuation safe zone to each road intersection. The Closest Facility function in Network Analyst provides the shortest route to each intersection from the safe zone. Figure 3.6 displays routes (symbolized according to closest facility) that were generated for the 11 individual evacuation sites to their closest safe zone. The sample size of cell phones in New York City would be significantly

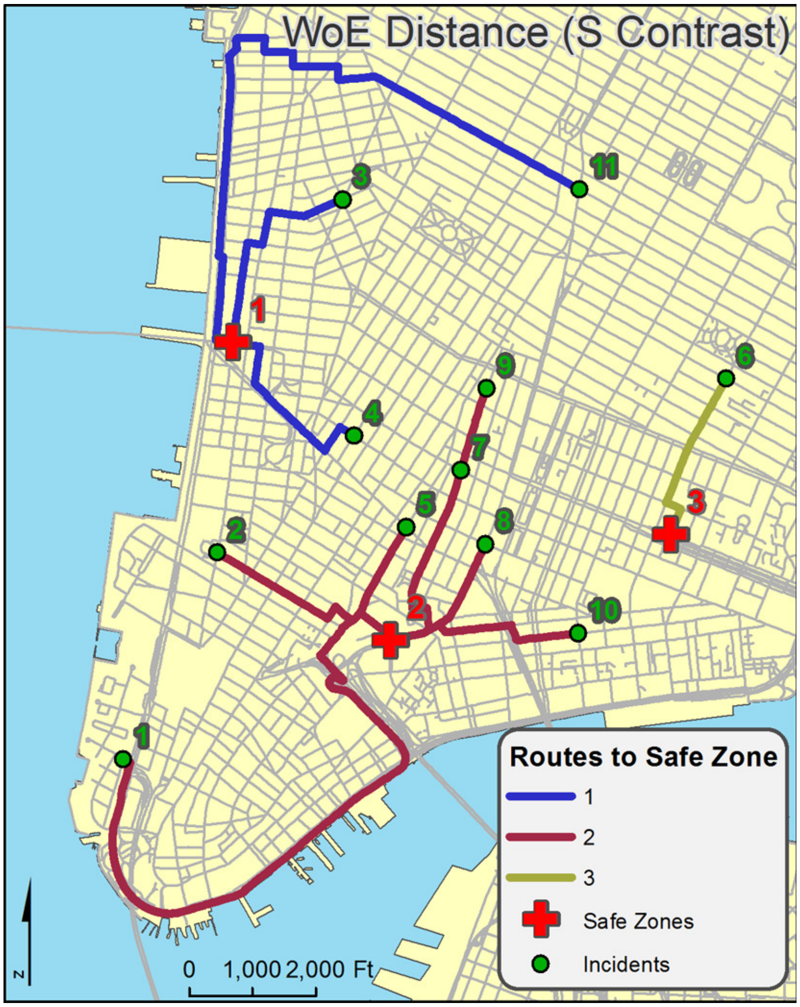

Figure 3.10: Best Routes Using Weights of Evidence - Distance and S_Contrast

larger and require significant computing to solve the routes for each cell phone. In order to minimize the complexity of the methodology, routes from the road intersections are determined and cell phones are assigned to the closest intersection providing an individual with an evacuation route.

The closest road intersection for each cell phone was determined using a spatial join. Each cell phone is matched to the closest road intersection (node) and the attributes of the node (including route from that node to the closest safe zone) are assigned to that cell phone. The final step is exporting the data in a format that can be shared with emergency service

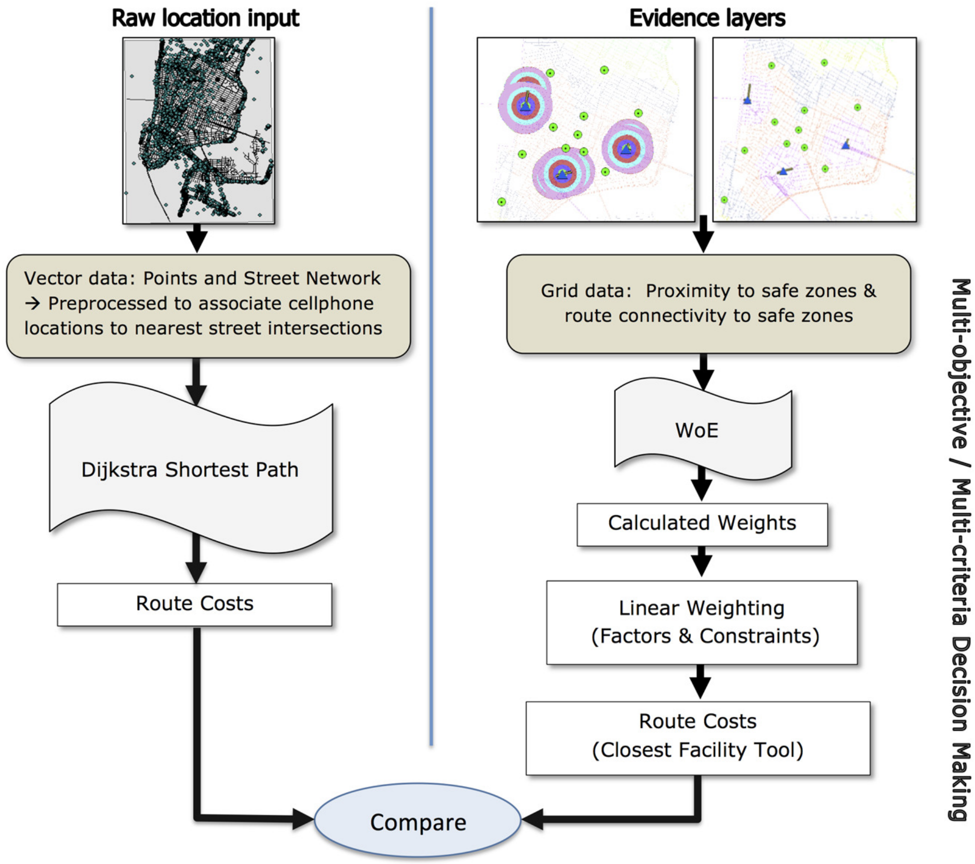

Figure 3.11: Methodology Chart

personnel and others in order to broadcast evacuation routes. Emergency planners can also use this data for determining where to position police checkpoints or to send ambulance vehicles, paramedics, and other response vehicles.

3.5 Case Study Used for Analysis

3.5.1 Study Area and Data

New York City was selected as a study area for this research. The study area is approximately 4512 acres. Street networks were collected from the New York City Data Mine and used to create a network data set in ArcGIS (New York City, 2011). Street data includes the bridges from Manhattan to NJ and the other boroughs in NYC. Census data was collected of the evacuation area for mapping the city boundaries (U.S. Census Bureau, 2011). Data is mapped using the New York Long Island State Plane Projection, NAD 1983. See Figure 3.1 for map of study area, along with street network, and cell phone locations used in this research.

Cellular phone location data was downloaded from OpenCellID, a database that provides open source cellular location data (OpenCellID, 2011). A total of 16,597 cell phone locations were used in the analysis. The data attributes include: Id (individual row identity) Latitude, Longitude, Mobile Country Code (MCC), Mobile Network Code (MNC), Location Area Code (LAC), id_of_cell (identification number for mobile phone), extraInfo (miscellaneous field), created_at (date when collected), and signal (measure of signal strength).

3.5.2 Information Dissemination - Output

This methodology determines the best routes from each cell phone location to the closest safe zone (three total safe zones). The results of this study identified evacuation routes for 15,000 cellular phone locations. The .dbf file that was produced contains the route name, cell id, and route directions. After the optimal route was identified for each phone location, the information can be converted to other formats, such as KMZ so it can be shared with emergency services personnel and individual cell phone users.

Table 3.2: Cost to Travel From Each Incident to the Closest Safe Zone

Incident	Safe Zone	Cost(Distance)	Incident	Safe Zone	Cost(Congestion)
1	2	5820	1	1	0.002027
2	2	3355	2	1	0.000015
3	1	3576	3	1	0.000011
4	1	2934	4	1	0.002098
5	2	2215	5	2	0.001085
6	3	2896	6	3	0.00001
7	2	3483	7	2	0.000009
8	2	2327	8	2	0.000008
9	3	4547	9	2	0.000013
10	3	2996	10	2	0.000012
11	3	7256	11	3	0.000425

3.5.3 Analysis

In Figure 3.5, the best routes are determined for each incident site using the criteria of minimum distance to the closest Safe Zone. In Figure 3.6, routes are determined by minimizing congestion from each incident to the closest Safe Zone. There are significant differences in the routes between Figure 3.5 and Figure 3.6. Using congestion as a measure increases the distance traveled for all routes except the route from Incident 6 to the closest Safe Zone (see Table 3.2). The remaining routes increase the distance traveled, ranging from 0.43% to 120% with a mean increase of over 29% in distance. Determining the best route by minimizing congestion and total distance traveled resulted in a slight increase (0.09% average for the 11 incidents) in the total distance traveled. The largest increase in distance traveled was less than 1%. Distance traveled will change as congestion varies within the city street network (i.e. rush hour traffic, snow storm, protest, parade, etc.).

The weights calculation from the Weight of Evidence method was used to measure congestion and the spatial association of the number of cell phone users to the street network (using two geographic feature layers) for the variable of S Contrast. Weights of Evidence is used to measure the association between the distance from the incident to the Safe Zone for variables of congestion and S Contrast (See Figure 3.7 and Figure 3.8). Congestion is measured as the number of cell phone users who have been located within an area and distance is measured using Manhattan Distance. There are significant changes in the routes using Congestion and S Contrast parameters, resulting in three of eleven incident routes being redirected to a different safe zone (see Table 3.3 and Table 3.4).

Table 3.3: Weights of Evidence Distance from Incident to Safe Zone

Incident	Safe Zone	Congestion	Incident	Safe Zone	S_Contrast
1	2	0.2182	1	2	1.9386
2	2	0.1075	2	1	1.6885
3	1	0.1237	3	1	1.37
4	1	0.105	4	1	1.3945
5	2	0.0642	5	2	1.5051
6	3	0.097	6	3	1.6627
7	2	0.0973	7	2	1.4835
8	2	0.0902	8	2	1.4698
9	2	0.1369	9	1	1.468
10	3	0.0756	10	2	1.5776
11	1	0.1819	11	1	1.5124

In Figure 3.7 and Figure 3.8, the congestion and S Contrast variables were calculated using the Euclidean distance from the safe zones. Safe zone 2 is the closest safe zone for 7 of the 11 incident sites when minimizing cost on the routes using congestion and S Contrast, respectively. In Figure 3.7 and Figure 3.8, the routes are very similar; however, there are some slight changes in the routes. For example, the route for Incident 5 in Figure 3.7 initially travels south, whereas in Figure 3.8, it initially travels to the east.

The evaluation criteria were used to determine the best routes individually. Figure 3.10 displays eleven (11) linear weighted evacuation routes. As a direct result of using a multi-criteria, multi-objective approach, the linear weighted cost is reduced over 19% from the cost calculated when determining the routes using only the minimum distance calculations as the base case (Figure 3.5). As expected, this results in an increased distance traveled

Table 3.4: Weights of Evidence Road Distance

Incident	Safe Zone	Congestion	Incident	Safe Zone	S_Contrast
1	2	0.7016	1	2	0.845
2	2	0.4379	2	2	0.48
3	1	0.3425	3	1	0.4604
4	1	0.2977	4	1	0.4077
5	2	0.2977	5	2	0.3103
6	3	0.431	6	3	0.4566
7	2	0.2705	7	2	0.3583
8	2	0.2433	8	2	0.3089
9	2	0.4234	9	2	0.5577
10	2	0.2954	10	2	0.459
11	1	0.723	11	1	0.7223

Table 3.5: Evacuation Route Impedence for Sample Sites

From Incident	To Safe Zone (Distance)	Impedance - Length		To Safe Zone (LW Score)	Impedence - LW Cost	
		LW Cost	Length		LW Cost	Length
1	2	64.64	5820.46	2	49.73	10976.35
2	2	24.72	3354.61	2	23.52	3468.49
3	1	22.62	3575.98	1	21.01	3619.04
4	1	28.71	2934.08	1	22.44	3287.15
5	2	24.04	2214.89	2	19.19	2677.95
6	3	25.03	2896.27	3	25.03	2896.27
7	2	20.13	3483.50	2	20.13	3483.50
8	2	20.76	2326.97	2	17.99	2848.55
9	3	47.44	4547.28	2 *	28.80	4846.37
10	3	37.39	2996.10	2 *	24.94	3411.74
11	3	55.71	7256.37	1 *	46.44	11380.80

(increase of 27% for the 11 sample incidents), with a prime advantage of a safe evacuation.

3.6 Conclusions and Future Work

Currently first responders and emergency response planners plan evacuations based on census data and updated population estimates for evacuation zones. This research methodology provides a means for sharing additional information with emergency personnel during their response to an emergency or disaster. It also provides a more efficient means for determining best routes for evacuees based on their cellular location. This research serves to provide first responders and emergency evacuation planners with a more informed decision-making process as well as provides evacuees with a safe and efficient evacuation route.

Evacuation planning and response for tragic events, such as Hurricane Katrina and the Japanese Tsunami highlight the need to take into consideration human behavioral aspects of Altruism, Normalcy bias, and Collective Syncing. The need to model these parameters in emergency response plans and models is critical. However, an alternative in leveraging mobile connectivity and ubiquitous computing can also be an effective means for evacuation planning and to help guide individuals during emergencies.

Future research in evacuation planning should include the development and integration of dynamic data with methods for sending critical evacuation related broadcasts and routing to individual cellular phones in an emergency. Visualization techniques for presenting evacuation routes on mobile devices such as smart phones, tablet computers, and laptop computers should be further researched. Additionally, the use of social network analysis to understand communication within families, friends, and employee networks during emergency situations is critical. This is especially true for people with disabilities and the elderly. Future research should also develop methodologies for sending aggregated location data to Emergency–911 services in large–scale disasters or emergency situations, which could provide for more accurate population estimates, regardless of spatio-temporal changes. With mobile penetration rates exceeding 100% in the U.S., mobile phones provide an excellent opportunity to explore additional methods for estimating population totals and diurnal population change with commuting / work schedules and during major events (International Telecommunications Union, 2011a). Understanding the challenges of sending possibly millions of messages and associated data through the cellular network requires some additional though into the prioritization of voice and data during an event. Policies that prioritize emergency service voice and data transmissions should be implemented and a protocol for implementing these policies should be understood by all companies (i.e. telephone, Internet, data providers, among others), and government agencies. Finally, researching the scalability of this methodology will determine the key factors that limit the number of people that are notified and receive evacuation routes during an evacuation.

In countries with limited resources, access to a mobile cloud-based decision support tool would greatly enhance the response and awareness of emergency services. In underdeveloped countries, this scheme could prove beneficial to Non-Government Organizations (NGOs) for estimating resources to respond to human needs. In conclusion, the privacy of individual locations collected during emergency planning and operations should be safeguarded.

Chapter 4: Analysis of Social Media Data to Reduce Risk During No-Notice Evacuations

4.1 Abstract

From the 2007 Virginia Tech shooting to the 2011 Japanese earthquake and Tsunami, social media have been used to generate a wealth of data and information. However, only a small number of relatively limited techniques have been developed to integrate social media into the emergency management cycle immediately following a no-notice disaster. In no-notice evacuations, citizens are faced with determining whether or not to evacuate. When evacuating, evacuees determine the shortest and safest route to a safe zone. In October 2012, emergency managers from Federal and local agencies participated in an Simulation Experiment (SIMEX) at George Mason University to determine how social media can be utilized to improve situational awareness. The SIMEX was conducted using the Citizen Emergency Response Portal System (CERPS), which collected and shared information between the EOC and participants. Chirp is a social media platform similar to Twitter; however, Chirp is a closed system that reduces the likely-hood that the simulation is mistaken for a real event, possibly leading to the Orson Welles effect (Leaming, 1995). Over 200 volunteers participated in this exercise. The goal of the simulation was to demonstrate the viability of receiving volunteered information from citizens during an emergency. This study analyzes social networking data from the simulation to determine locations of reported incidents and map the risk to evacuees. Evacuees are notified to shelter in place if they are within a high-risk area. Citizens who can evacuate with minimal risk are identified and routed to safe zones while avoiding high-risk areas.

4.2 Introduction

Citizens and government agencies increasingly use social media and mobile applications to communicate during crisis events (American Red Cross, 2012; Hughes and Palen, 2012). In 2012, over 20 million tweets were sent about the Hurricane Sandy (Olanoff, 2012). Social networking sites, such as Facebook and Twitter, are used to update friends, family, and co-workers and provide an alternate method to update large numbers of people with one message as compared to making multiple phone calls. In the United States and many other countries, local and state emergency management agencies have established a presence on social media, primarily to disseminate information to citizens. Building a social media presence prior to a disaster or emergency creates online credibility for government agencies and non-profit organizations. With a credible social media profile, agencies increase the network of followers who will share, re-tweet, or respond during an emergency providing an alternate means of two-way communication.

Craig Fugate, the Administrator of the Federal Emergency Management Agency (FEMA), said "individuals, families, and communities are our nations first first responders. The sooner we are able to ascertain the on-the-ground reality of a situation, the better we will be able to coordinate our response effort in support of our citizens and first responders" (U.S. Congress, 2011). Further he states that FEMA values two-way communication from all sources and that cell phones and social media have provided new methods of communication. Finally, he encourages state and local agencies to communicate with the public through the use of social media sites.

Internationally, government agencies are focusing their efforts on using social media to inform communities and as a multi-directional sharing platform during emergencies (NGIS, 2009; U.S. Department of Homeland Security, 2012). Many government agencies are concerned with the reliability and validation of crowd-sourced information and the challenges of filtering information from social media feeds (NGIS, 2009). The Australian Government developed the report "Social Media helping Emergency Management" and following the 2010 earthquake in Christchurch, the New Zealand Government developed "Social Media in an Emergency: A Best Practice Guide" (NGIS, 2009; Rive et al., 2012). Realizing the importance of social media as an alternate means of communication, these reports seek to enhance the use of crowd-sourced data by government agencies and to enable the development of new methods that will help save lives and reduce property damage in future emergencies.

Geographic Information Systems (GIS) are robust tools that support emergency response, evacuation planning, collecting and analyzing data from citizen sensors, risk mitigation, and emergency communication (Cova and Church, 1997; Cova, 1999; Zarcadoolas et al., 2007; Goodchild, 2010). Although GIS provide increased support and more efficient workflows, challenges exist with implementing GIS so that lesser-educated citizens can understand digital and paper-based GIS products (Zarcadoolas et al., 2007). Zarcadoolas et al. found that over 83 percent of lesser-educated participants in their study could not identify their evacuation zone. With smartphone saturation rates of over 50 percent in the U.S. and numerous mobile applications that provide GIS enabled features, researchers and developers have the tools and knowledge to better inform citizens during evacuations. The Federal Communication Commission (FCC) in coordination with the FEMA, recently developed Wireless Emergency Alerts (WEA). WEA is also known as the Commercial Mobile Alerting System (CMAS) and Personal Localized Alerting Network (PLAN). WEA is a tool that notifies citizens with a 90 character message, similiar to a text message, but WEA messages have higher network priority than text messgages. The messages are sent based on their mobile device's location (Federal Communications Commission, 2013; CTIA - The Wireless Association, 2013). Integrating WEA, smartphones, and social media to support crisis events enhances multi-modal two-way communication between federal, state, and most importantly local authorities and citizens and increases situational awareness.

Social media provides near real time data on crisis events, enabling emergency managers the ability to communicate with citizens through mobile phones and mobile applications. Various techniques have been developed to extract information from social media feeds to improve situational awareness (Palen et al., 2010; Stefanidis et al., 2011). Zhao et al.'s

(2011) recent work demonstrated a technique that detected events using Twitter within 40 seconds of the event. Near real-time detection of events techniques leads to the question, how can we use the data gained from such events to minimize risk to citizens during crisis situations. This research introduces a method to model risk within an urban area using social media. The risk model is used to notify citizens within the evacuation zone to shelter in place or to evacuate using a route that minimizes risk and distance traveled.

The following sections provide an overview of mobile device use during emergency evacuations and the value of social media during a no-notice emergency evacuation.

4.3 Mobile Device Use During Emergency Evacuations

In New York City, the percentage of 911 calls from mobile phones have increased from 29 percent in 2003 to almost 59 percent in 2010 (Gonzalez, 2012). Although there are concerns with using social media during an emergency, there are similar issues with mobile devices. In 2010, New York City received over 4 million false calls, many of them occurring when users accidentally call 911 when their phone is in their back pocket, commonly known as a butt call (ibid). Similar challenges exist in Britain, where less than 25% of over 7.5 million emergency calls turned out to be real emergencies (Boyle, 2012). As with land-line phone calls, mobile phones have introduced false alerts into the 911 system; however, emergency personnel have developed procedures to address false reports. Similar procedures are needed to address the use of social media during emergency situations.

The Federal Communications Commission (2012) announced that 911 text messaging would be available nation-wide in May 2014. This will provide increased capabilities to 911-call centers to monitor networks. Although text messaging provides another method of notification, it does not address situations when phone service is disrupted. In 2012, Fairfax County experienced a full outage of 911 services for over 7 hours with some 911 services not restored for over 4 days (Callahan, 2012; Flaherty, 2012). Using social media platforms that can be accessed through an Internet service provides an alternate communication method for citizens.

Many universities have already integrated notification methods to text students and faculty during emergency situations. Sattler et al. (2011) found that with prior planning text messages provide an effective method to notify faculty and students at a university campus. Their study found that 95 percent of participants complied with the recommended actions in text and email messages they received during an active shooter simulation.

Following the 2011 Japanese earthquake, the Japanese government and its citizens realized the importance of social media to share information when many phone networks were damaged or overwhelmed with too many callers (Wallop, 2011). In 2012, the Japanese government collaborated with Twitter to conduct an exercise that evaluates techniques for integrating Twitter into a notification and communication platform during earthquakes and tsunamis (Russell, 2012; Panzarino, 2012).

4.3.1 Contributions of Social Media in Emergencies

Immediately following a no-notice emergency, limited information is available about the event (as shown in Figure 4.1). After emergency response personnel and managers determine what has occurred, they begin informing citizens of what steps to follow and also inform media outlets of messages to release to the public. Immediately following an incident is the most critical time to notify individuals of what has occurred and how they should respond; however, traditional methods are slow to release official information regarding an incident, whereas social media reporting often occurs much quicker (Zhao et al., 2011).

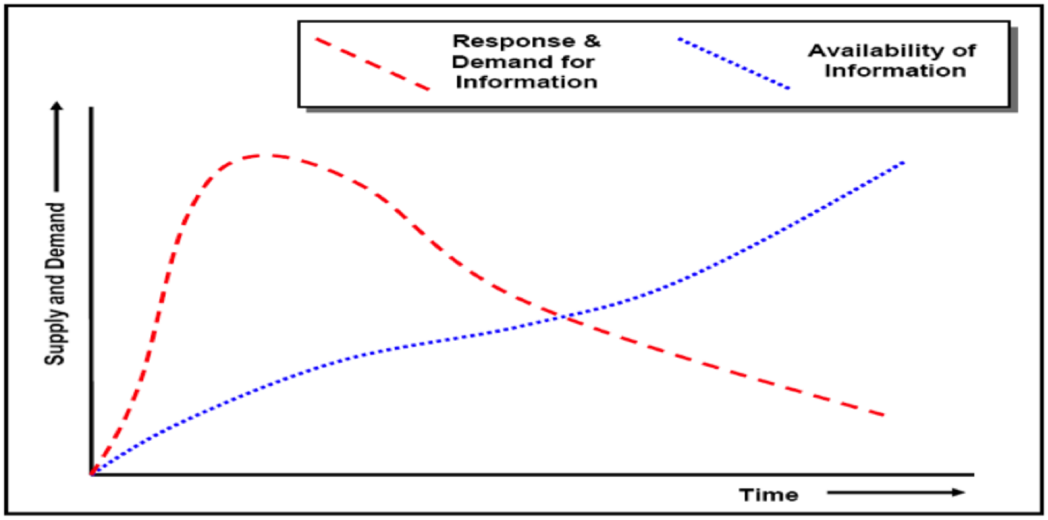

Figure 4.1: Demand for Information versus Information Availability Following an Emergency (Source: Olafsson, 2010)

On March 18th, 2013 at the University of Central Florida, a student pointed a weapon at his roommate around 12 AM. Students living on campus received and shared messages through Twitter (as early as 12:56 AM) before receiving notification through the campus email messaging system (emails sent at 2:10 AM) (as shown in Figure 4.2). Although many students were notified by the universities' email messaging system, many students received notifications through social media before the 'official' notification from the university.

Lindsay (2011) evaluated the current use, future options and policy considerations for social media support in emergencies and disasters. Lindsay considered two broad categories of use for social media in emergencies and disasters. The first involves the use of social media by government agencies in a passive role, primarily disseminating information and receiving feedback through messages, posts and polls/surveys. The second approach involves a systematic use of social media including:

- Using social media for emergency communications and to issue warnings
- Receiving requests for assistance from victims

Figure 4.2: University of Central Florida Notifications, March 18, 2013 – Unofficial notification through Social Media vs Official notification from the University through Email

- Increasing situational awareness by monitoring social media
- Improving damage estimates with photos and video from social media

Significant changes have resulted as a result of social media use during emergencies; however, many emergency managers have not accepted social media as an additional method of engaging the public (For-mukwai, 2010). Although many emergency managers primarily use social media to disseminate information in a passive role, there has been a shift to more active use of social media as a communications platform enabling victims to request assistance, share photos and video with FEMA and to increase situational awareness for citizens and emergency personnel. Castillo et al. (2011, 2013) recently introduced a method for predicting information credibility in social media during emergency and crisis situations. Castillo et al. (2011) found 86% ROC (receiver operating characteristic curve) for English tweets and 82% ROC for Spanish tweets. ROC is a measure of the true positive rate against the false positive rate, providing a measure of the predictive quality of their model.

Immediately following the 2011 Japanese earthquake, when phone lines were damaged, many Japanese citizens used social media to share messages with others about what happened and if they were safe (Winn, 2011; Taylor, 2011). Twitter reported a 500 percent increase in tweets from Japan following the earthquake and spikes of over 5,000 tweets per minute (Chowdury, 2011). Since the 2011 Earthquake, the Japanese government conducted an earthquake drill to test messaging with over 100 citizen volunteers. Twitter messages during the drill included notifying citizens of evacuation shelters, appropriate evacuation routes, and injuries (Russell, 2012).

From October 27th through November 1st, 2012, over 20 million tweets were sent discussing Hurricane Sandy. The Red Cross monitored over 2.5 million Hurricane Sandy messages and responded to 4,500 of them on-line or in person. NYC Digital shared information in over 2,000 tweets in English and Spanish (Baer, 2012). Following the 2011 Virginia earthquake, many phone networks in the State were overwhelmed by the increased number of phone calls and many found it difficult to impossible to make a phone call. Many people turned to social media to let family and friends know they were okay. Some government agencies encouraged citizens to use social media instead of reducing network reliability by making voice calls. The Department of Homeland Security turned to social media, instead of traditional media and tweeted to its followers: "Quake: Tell friends/family you are OK via text, email and social media (@twitter & facebook.com). Avoid calls" (McCarty, 2011).

Social media is a valuable source of information for citizens and emergency personnel; however, additional improvements to filtering and analyzing the massive data sets are needed. Schnebele and Cervone (2013) introduce an innovative approach to fuse volunteered geographic information and remote sensing data to improve situational awareness during flooding. Using Youtube and Flickr data, Schnebele and Cervone, reduce spatial and temporal gaps and improves flood assessments. Additional improvements to spatial, temporal, and contextual filtering methods are needed to extract and analyze the appropriate data leading to improved situational awareness.

4.3.2 Concerns of Emergency Managers and Citizens During a No-Notice Evacuation

Social media networks are playing a greater role in emergency scenarios. Citizens use social media to report information and they believe that response organizations should be monitoring social media during disasters (American Red Cross, 2010, 2011b). A 2012 survey by the American Red Cross found that mobile applications and social media are tied as the fourth most popular way to get information during an emergency (American Red Cross, 2012). The American Red Cross survey also found that over 76 percent of users expect to receive help in less than 3 hours after posting a request on social media platforms. Most emergency managers have been slow to integrate social media into disaster response; however, efforts such as the American Red Cross Digital Operations Center and Virtual Operations Support Teams are forging new methods and techniques for integrating social media into emergency response.

In March 2011, Jeff Phillips developed and tested the concept of a Virtual Operations Support Teams (VOST). In emergency management and disaster recovery, VOSTs make use of new communication technologies and social media tools so that a team of trusted agents can lend support via the internet to those on-site who may otherwise be overwhelmed by the volume of data generated during a disaster (Stephens, 2012). VOSTs have been integrated into Emergency operations supporting several events including Hurricane Sandy, Hurricane Irene, and the Shadow Lake Wildfire (St. Denis et al., 2012; Stephens, 2012). St. Denis et al. (2012) highlight several key VOST objectives:

- Monitoring social and traditional media and reporting trends
- Communicating issues and concerns expressed by the public
- Identifying misleading information and addressing the concerns of citizens
- Working with the Public Information Officer to synchronize reporting through social and traditional media outlets
- Documenting information and trends from social media

Many of the efforts of implementing social media to support crisis communications and response, such as VOST, have occurred as a result of self-organized groups of individuals who were concerned with providing accurate information to citizens in a timely manner to reduce injury and death and to respond to calls for assistance.

4.4 CERPS Simulation Experiment (SIMEX)

On October 1-5, 2012, emergency preparedness experts gathered at George Mason University to conduct a Simulation Experiment (SIMEX). The purpose of the SIMEX was to evaluate the effectiveness of social media during emergency response. The SIMEX supports Presidential Directive-8: Our national preparedness is the shared responsibility of all levels of government, the private and non-profit sectors, and individual citizens. Everyone contributes to safeguarding the Nation from harm (Obama, 2011). During the simulation, over 200 students responded to simulated explosions, shootings, hostage situations, and fires on the George Mason University Campus. The students communicated with each other and emergency personnel through a Twitter-like platform known as Chirp. The Citizen Emergency Response Portal System (CERPS) collected and shared the chirps with emergency managers, operators and public information staff from the City of Alexandria, Fairfax County, George Mason University, Virginia Department of Emergency Management, National Guard Bureau, Department of Defense, and the Federal Bureau of Investigation (Wright, 2012).

The Citizen Emergency Management Portal enabled students participating in the exercise to view a simulated environment through the Simulated Sensory Environment (SSE) in Figure 4.3. As students observed day-to-day activities and incidents occurring from their simulated position on campus, they could post messages using Chirp. Chirp is a Twitter-like application that allows users to post messages. Chirp provided a medium for two-way communication with the Emergency Operations Center (EOC) and other students.

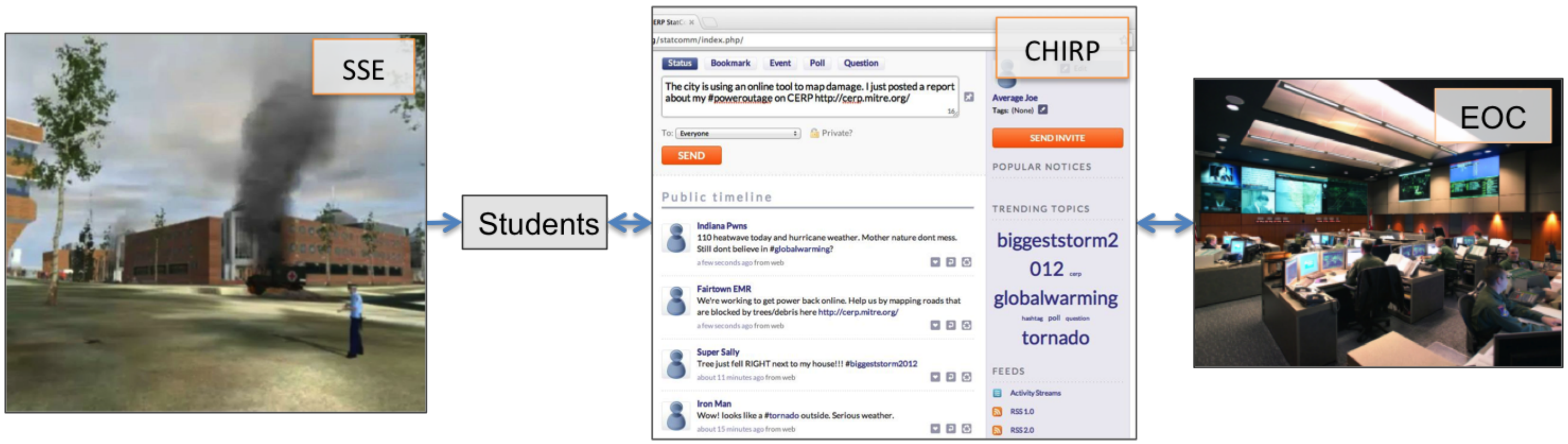

Figure 4.3: Overview of Citizen Emergency Response Portal

4.4.1 Study Area and Data

The study site for the analysis reported here is George Mason University (GMU) located in Fairfax, Virginia. The main campus is over 677 acres. The university serves over 32,000 students with over 5,700 living on campus (George Mason University, 2012). Esri shapefiles were downloaded from the George Mason University library. Data was originally published in 2005, including building footprints, hydrology, orthophotography, parking, paved areas, roads, stairs, and walk ways. Building footprints, parking, roads, and walk ways were revised in 2009 (George Mason University, 2009).

The Mitre Corporation provided Chirp data from the simulation experiment. Over 6,700 Chirps were collected during the simulation experiment described above. The Chirp data included: user nickname, user ID, message content, and message date/time (as shown in Table 4.1).

Table 4.1: Sample Chirp Data from CERPS Simulation Exercise

Nickname	Id	Content	Modified
harrypotter613	1832	#explosion at the #RAC. Stay away!!!!	3/10/12 14:39
rpetersh	1828	I see an active fire at the RAC and police personnel #SNN	3/10/12 14:39
ada1ovelace	1836	Did any #911 make it to Innovation yet to investigate the possible gunshots?	3/10/12 14:40
cre146	1835	It's the RAC	3/10/12 14:40
lg678	1838	RT @harrypotter613 #explosion at the #RAC. Stay away!!!!	3/10/12 14:41
gmu	1845	Another #explosion has been confirmed on the GMU Fairfax Campus near the Recreation and Athletic Complex continue to #shelter in place	3/10/12 14:42

4.5 Objectives

The primary objective of this research was to model feature-based static risk during an emergency evacuation using social media. Evacautions during a no-notice evacuation seek to maximize the number of people evacuating or minimize the number of casualities or exposure to risk in the incident area (Chiu et al. 2007). The intent of this risk model is to minimize casualties and minimize exposure to incidents occurring within a no-notice emergency, such as a terrorist attack.

4.5.1 Methodology

The first step in this research is to mine the data for incidents and locations. Mining the Chirps data included two steps: a hashtag/keyword search and geo-parsing the messages. The first step included searching for hashtags and keywords that identified emergency incidents. Some examples of hashtags and keywords include: fire, 911, explosion, bomb, shooter, gunfire, shooting, and others. Extracted messages are sorted according to incident type, date and time.

The next step was to parse the Chirp messages. Facility and building locations for George Mason University were matched against text within the messages to match features within the messages to geographic features in a dataset. Then Chirp messages were searched to determine what location attributes where found within the messages that identified where the incidents occurred.

As part of the CERPS Simulation exercise, the data collected did not have geographic locations (i.e. latitude and longitude) included in the metadata. However, volunteers during the event often messaged others with information on incidents and the location. The Chirps data was parsed to extract locations of the incidents from the messages. George Mason University buildings and facilities were used to determine locations of incidents across the campus. Numerous types of incidents were identified (Table 4.2). The methodology section below analyzes data from October 3rd. On October 3rd, six major incidents were identified and located. The incident locations were assigned to the associated facility or building footprint. The six incidents included an explosive device at the Recreation and Athletic Complex (RAC), a fire at David King Hall, a shooting/hostage situation at Innovation Hall, and suspicious backpacks/backpack bombs at Fenwick Library, the Johnson Center, and Research 1. The reported incidents occurred starting at 9:28 AM with messages received until 3:31 PM(See Table 4.2).

Table 4.2: Incident Locations, Incident Type, and Times for October 3, 2013

Location	Incident Type	Time messages received
Johnson Center	Explosion	0928 - 1104
David King Hall	Fire	1010 - 1014
Research 1	Backpack	1410 - 1416
Recreation and Athletic Center	Explosion	1434 - 1531
Innovation Hall	Shooting	1433 - 1443
Fenwick Library	Backpack	1428 - 1434

Emergency evacuations are inherently dangerous situations, especially in no-notice evacuations. Dyck (2006) defines risk as a measure of the probability and severity of an incident within the hazard zone. In this study, risk is defined as the likelihood that threats occurring at the incident(s) may cause injury or death to an individual at a location within the study area. Equation (4.1) determines the maximum risk for each incident that a citizen may encounter along a route.

$$R = s_p \frac{T_p}{d} \tag{4.1}$$

s_p is a measure of severity for each incident p. T_p is the maximum distance away from the incident that injury or death may occur. d is the distance from the closest point on the road or sidewalk to the incident. Risk for incident p is calculated for all road vertices where d is less than T_p feet from incident reported location. Features associated with the incident p maybe represented as polygon or point features. For example, messages with geographic coordinates (e.g. Latitude, Longtitude) are recorded as point features. Reports that include feature-based locations (e.g. Johnson Center) would be represented as polygons. The Chirps data did not have any coordinate data associated with the messages, therefore incidents are represented as polygons.

Clauset et al. (2007) analyzed 10,878 terrorist events (occurring from 1968-2005) that resulted in injury or death, including small to large-scale events. They sought to determine a mean measure of severity for different types of terrorist events. Clauset et al. sought to produce an accurate severity distribution for different terrorist events to better determine how severe terrorist events are likely to be. The severity measure used in this research is based on the work of (Clauset et al., 2007). The mean severity values, in Table 4.3, are used as severity measures (s_p) in this study.

Table 4.3: Mean Severity for Global Terrorist Events Resulting in Injury or Death

Event Type	Number	Mean severity
Chemical/Biological	19	274.11
Explosives	4869	18.93
Fire	133	16.79
Firearms	4603	4.09
Knives	254	2.43
Other	1,000	9.30

Table 4.4 is a list of the distances used for T_p. These planning distances are derived from the Emergency Response Guide, U.S. Department of Transportation and the George Mason University Emergency Evacuation Guide. It is important to note that these planning distances may vary depending on local, state, or federal emergency response procedures.

4.6 Results

The following results represent the risk from events that occurred on October 3, 2012 during the CERPS Simulation Exercise. Figure 4.4 represents six major incidents that occurred at George Mason University. These images highlight the risk from each of the six incidents and can be used by emergency personnel for prioritizing response efforts, determining where individuals should shelter in place, and for evacuation planning.

Table 4.4: Outdoor Evacuation Distance

Incident type	Distance (feet)
Fire	100
Pipe bomb	850
Weapon/gun (pistol, rifle, shotgun)	1500
Sedan (Improvised Explosive Device)	1750
Briefcase/suitcase bomb	1850

Combined severity for multiple incidents within the same area were solved using Equation (4.2).

$$R_m = \sum_{1}^{n} s_p \, \frac{T_p}{d} \tag{4.2}$$

R_m represents the total risk on a path from all incidents. n represents the total number of incidents that are within T_p feet of each road/path.

In Figure 4.5, the left image represents the combined risk for the incidents that occurred on the morning of October 3. The morning incidents were reported from 0928–1104 (9:28–11:04 AM). The two incidents involved an explosion at the Johnson Center and a fire at David King Hall. The right image visualizes the combined risk from the four incidents that occurred on the afternoon of October 3rd. These incidents were reported from 1410–1531(2:10–3:31 PM). These incidents include a vehicle explosion at the RAC, a shooting & hostage situation at Innovation Hall, and reports of backpack bombs at Fenwick Library and Research Hall.

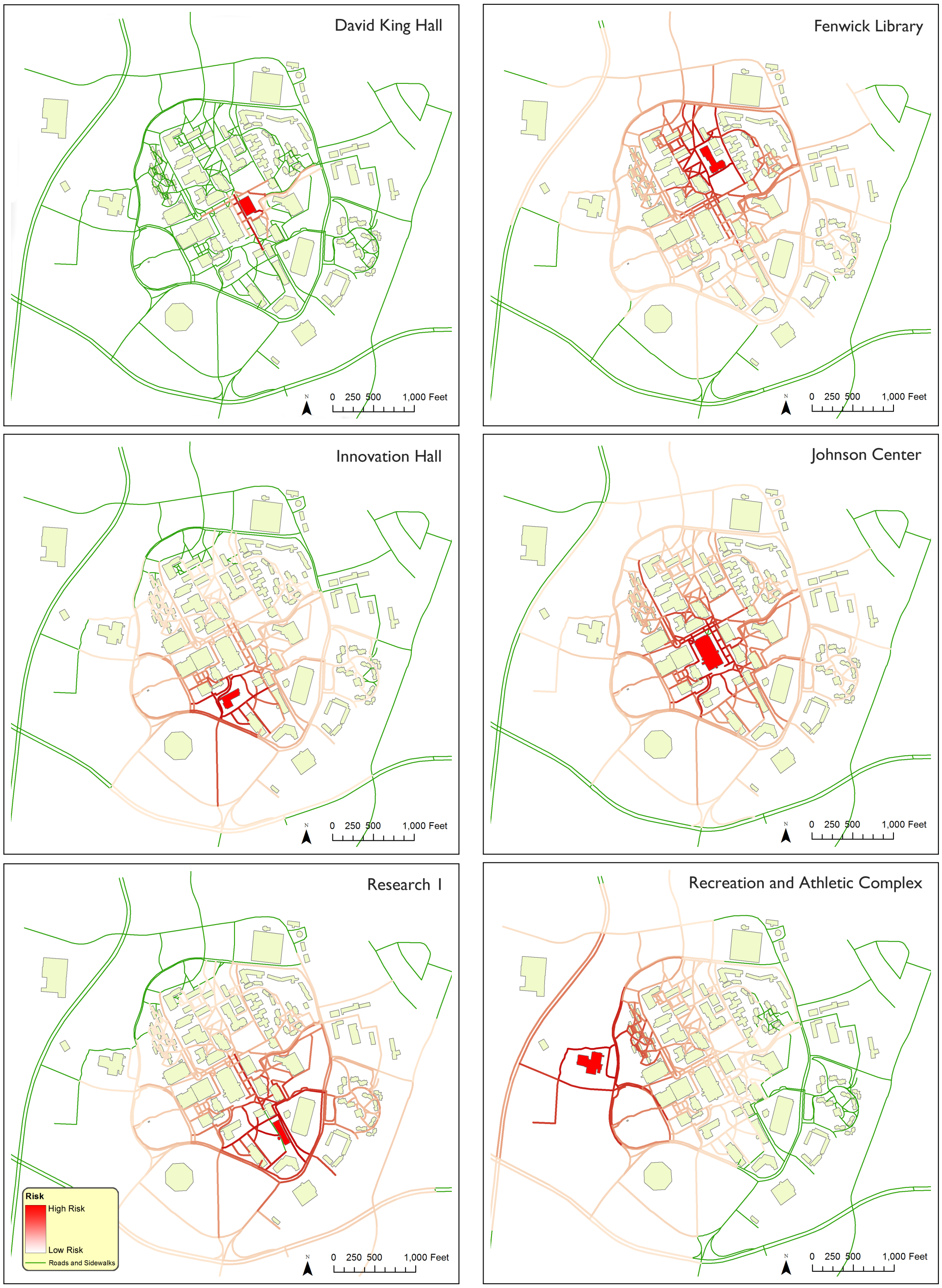

Figure 4.4: Risk for Individual Incidents During CERPS Simulation Experiment

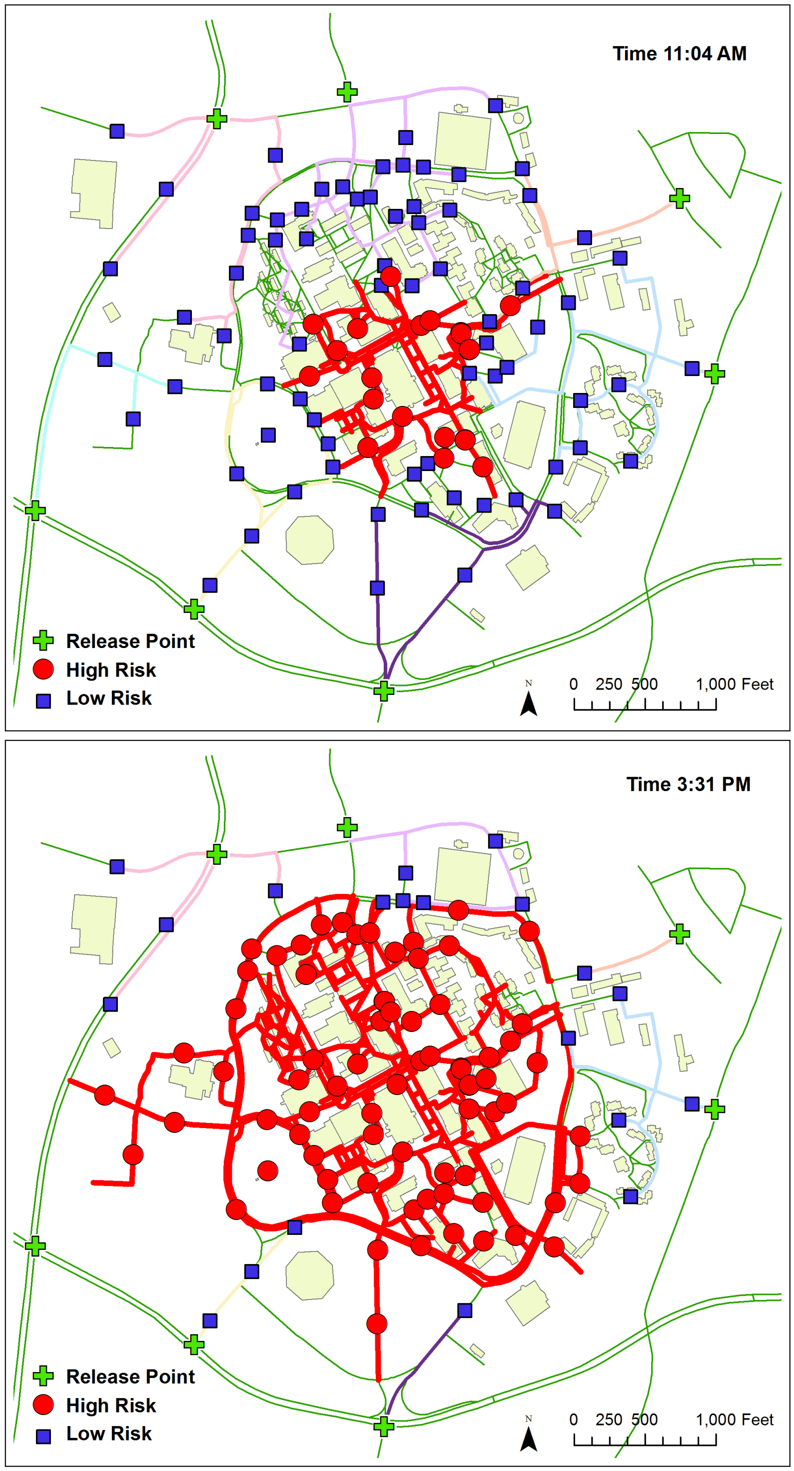

Figure 4.5: Risk for GMU Incidents as of 11:04 AM and 3:31 PM on October 3, 2012

Risk measures for individual routes for the two reported incidents as of 11:04 AM are shown in Figure 4.6.

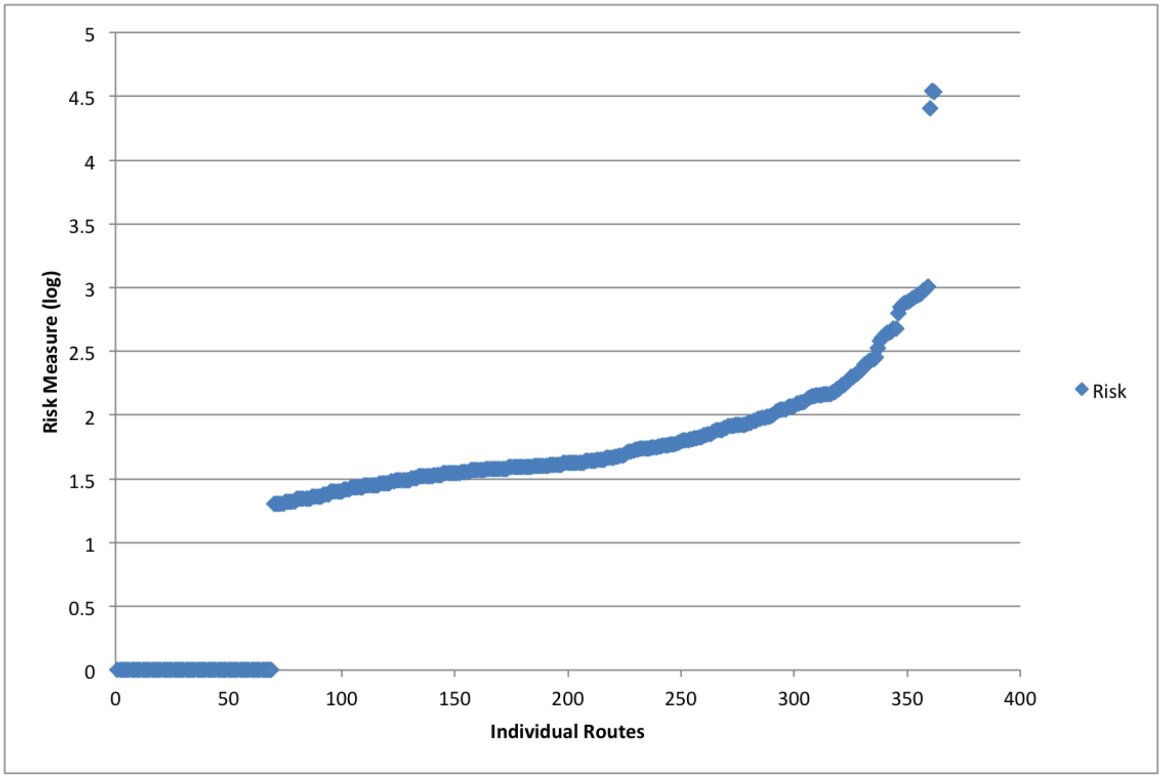

Figure 4.6: Risk for Roads and Paths at 11:04 AM

Measures of risk along individual routes for the four reported incidents as of 3:31 PM are shown in Figure 4.7.

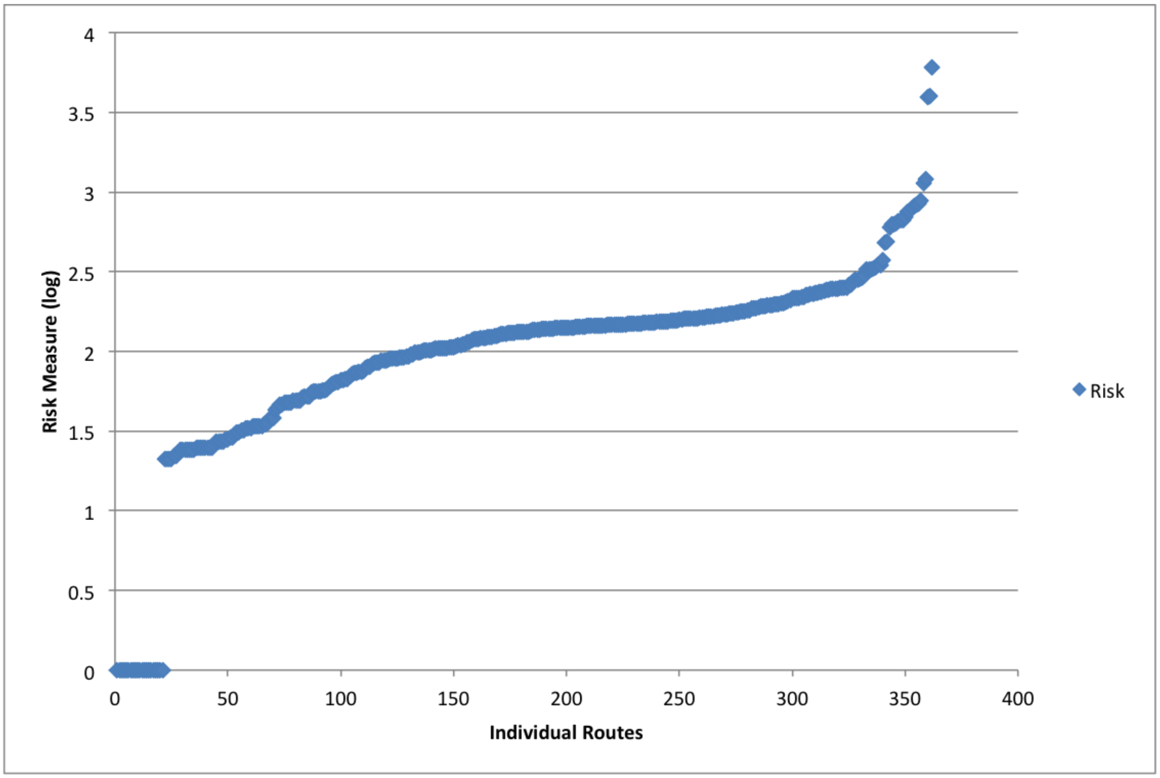

Figure 4.7: Risk for Roads and Paths at 3:31 PM

4.7 Future Efforts to Increase Social Media Use During Disasters and Emergencies

The use of social media provides a medium for improving situational awareness during disasters and emergencies and provides an alternate method of two-way communication with the public. Several efforts to improve situational awareness of the real-time disease have lead to increased situational awareness and risk reduction. Chunara et al. (2012) found that outbreaks of cholera could be monitored and estimated using social media data up to two weeks earlier than formal methods. Khan et al. (2012) introduces a method that classifies self-reported illness (flu) through twitter with an 88.7% precision. Integrating the efforts of Chunara et al. (2012) and Khan et al. (2012) into future research efforts may provide increased credibility, situational awareness, and risk reduction during a crisis. The next step in furthering social media use during emergencies is a coordinated effort by government and social media companies to build more trust in using social media as an alternate communication method, to establish policies that protect the privacy of citizens who use the social media, and to educate emergency personnel on methods for integrating social media into operations.

Through a collaborative effort, the integration of social media and mobile devices will provide citizens and emergency personnel with an additional means of communication. Mobile devices and applications also provide a platform for emergency personnel to minimize risk to citizens and first responders. During emergencies, damaged electric and communication lines often affect efforts to communicate with citizens through traditional media such as television and radio; however, many citizens update their status on social media sites and ask for assistance through social media.

Given the challenges of collecting and filtering social media and producing information that is beneficial to citizens and emergency personnel, the following recommendations are proposed to assist with increasing the adoption and acceptance of social media use during emergency evacuations:

- Social media sites should enhance methods for verification of social media accounts. One example includes verifying or linking a user's account to their mobile phone through a verification text message with a response to acknowledge the account.

- FEMA, in coordination with the FCC, should develop an emergency hashtag such as #911 and educate the public and emergency personnel on the use of it.

- Utilize social media, the Internet, and Wireless Emergency Alerts (WEA, previously known as the Commercial Mobile Alert System (CMAS)) to disseminate emergency hashtags during no-notice evacuations. Follow up with TV and radio dissemination.

- Coordinate with social networking sites to establish procedures that automatically encrypt location data for all emergency messages, posts, or tweets that use the designated emergency hashtag. Procedures should include methods for emergency operations centers to access location data for response.

- Establish methods that geo-fence social media data to enable emergency operations centers and/or 911 call centers to only receive emergency messages that are within their jurisdiction.
- Establish a Social Media Crisis Research Center that forms a collaborative research community for academics, corporations, non-government organizations, and emergency personnel to focus on harvesting social media, text extraction, geolocation, privacy, and the analysis of social media during and after crisis events.

4.8 Conclusion

Social media provides an opportunity to leverage millions of citizen-sensors to increase situational awareness during emergencies and disasters (Goodchild, 2007a). Castillo et al.'s (2013) recent advances in predicting credibility in social media during emergencies and Crooks et al.'s (2013) improvements to data mining techniques provide the opportunity to reduce risk to citizens and emergency personnel. Our research introduces a method for measuring risk using social media immediately after an emergency on a university campus. In this scenario, we detected six simulated incidents that occurred as part of the CERPS Simulation Experiment; however, additional research is needed to determine the feasibility of detecting real-world incidents using social media, with differences in the culture and languages used across the United States.

Chapter 5: Discussion

Citizens face increased risk during no-notice emergencies, yet they may lack situational awareness of what occurred or what actions to take. The most risk occurs immediately following the incident; however, traditional methods of notification can take one to two hours or longer. Citizens, non-government and government agencies would benefit from a common platform that identifies high risk areas and enabling emergency personnel to focus response efforts in those regions (Oxendine et al., 2012). As part of this effort, citizens should be educated on alternative methods of communicating risk during an evacuation resulting in increased awareness for their community and emergency managers during the next crisis. The discipline of geographic information science is ideally positioned to provide and coordinate these developments. Fusing Volunteered Geographic Information (Social Media and Mobile Phone Data) with additional data sources in the emergency operations center will increase situational awareness leading to reduced risk to citizens and first responders. International and domestic government and non-government agencies should place increased focus on integrating Social Media and Mobile Phone Data by:

- developing appropriate policies and procedures
- educating the public and emergency personnel on these policies and procedures
- integrate Social Media as an alternate communication method
- analyze Social Media and Mobile Phone Data with GIS

5.1 Policies and Procedures

Through a collaborative effort, the integration of social media and mobile devices will provide citizens and emergency personnel with an additional means of communication.

With increasing phone ownership, mobile phones and Social Media will increasingly affect emergency and crisis events. Policies and procedures need to be developed that address citizen privacy and the use of this data by emergency personnel. For example, in a terrorist attack, emergency personnel could use mobile phone location data to determine where people were located at the time of the attack? Which locations of a city had the highest population densities? Can emergency personnel use individual social media or mobile phone location data to determine the last known location of missing individuals? Although finding missing and injured during an emergency is a top priority, are we violating their privacy by tapping into their social media accounts? National, State, and Local government officials, in coordination with Emergency Managers, need to develop laws that address these and other questions.

5.2 Education on Social Media Policies and Procedures

To further integrate mobile devices into emergency response, efforts must be made to educate the public and emergency personnel. Citizens are concerned with their privacy if the government is tracking them. As National and International organizations and agencies develop Social Media Policies, it is imperative that they educate the public on how VGI is used to minimize risk during an emergency or crisis. Recent efforts, such as North Atlantic Treaty Organization (2012), provide forums to identify risk and benefits for using social media. It is important that this dialog continues internationally and domestically to ensure that emergency personnel understand and know the proper procedures to protect the privacy of citizens during a crisis event.

5.3 Social Media as an Alternate Communication Methods

Although New York City power outages following Hurricane Sandy lasted for over 5 days, there were still over 20 Million tweets that were sent between October 27th and November 1st (Olanoff, 2012). Instead of radio and television, many users used Social Media to maintain situational awareness during Hurricane Sandy. As seen in Figure 5.1, there was a slight increase in mobile Twitter traffic from October 27th to the 28th; however, on October 29th, there was a significant spike in traffic. Olanoff (2012) found that on October 29th, over 20% of Twitter's traffic was search queries. Twitter users were using the search and discover function to maintain situational awareness.

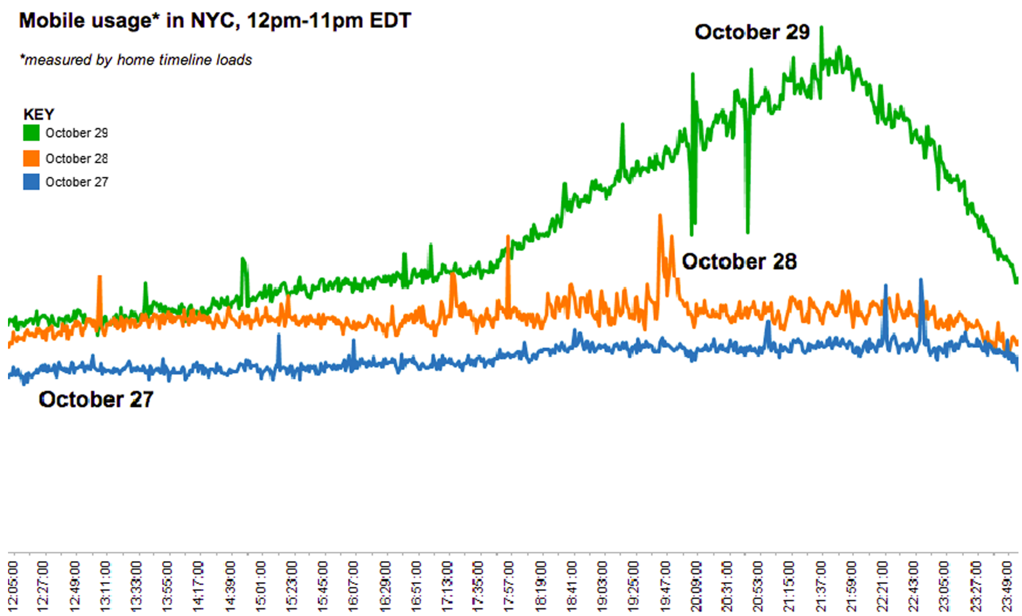

Figure 5.1: Mobile Twitter Traffic for October 27-29, 2012 (Twitter, 2012)

5.4 GIS Support to Reduce Risk in Emergency Evacuations

GIS provides a web-enabled tool that Emergency Managers can use to analyze and model risk during emergencies. During an evacuation, GIS provides the ability to publish maps and evacuations routes to smart phones and mobile applications, or directions can be provided that are text based for flip phones. As a complement to WEA, future research should focus on the development of a web-based, mobile GIS platform that supports notification, reporting, and evacuation routing. This tool would provide alternate means of two-way communication between citizens and emergency personnel. A communication platform integrated with spatial and temporal capability would increase situational awareness between National, Federal, and Local governments as well as Non-Government Organizations (NGOs). Before, during, and after an emergency, citizens would be able to find the closest open shelter, hospital, police or fire station from their current location. This tool should also be used to route citizens away from high risk areas during an event. Finally this platform should provide the ability for EOCs to only receive and analyze reports from citizens within their jurisdiction.

5.5 Research Contributions

Significant improvements in mobile technology over the past decade provide opportunities to drastically improve notification and reporting during emergencies. This research contributes to reducing the gap between research and applications by:

- providing a methodology that enables citizens to become sensors that can share intelligence with emergency services which in turn can be used to notify surrounding communities of impending hazards
- forging a new generation of emergency response alerting procedures, planning, and response in no-notice evacuations
- providing a model minimizes risk to evacuees in urban areas
- providing a model that reduces the likelihood injuries and deaths during and after a hazardous event

Analyzing mobile phone data and social media data enhances situational awareness of citizens and first responders during no-notice emergencies and crisis events. Further analysis is needed to examine how to integrate this information into the disaster management process. Finally, this research benefits many under-developed countries, where resources are limited. From 2005 to 2013, mobile phone subscriptions (per 100 inhabitants) in developing countries increased from 22.9% to 89.4% (International Telecommunications Union, 2013). In countries where communication methods are limited, mobile phones provide an alternate method of notifying many citizens who are at risk from a man-made incident or a natural hazard (e.g. a tsunami). This research enables emergency personnel to quickly identify high risk areas and prioritize the notification based on risk. Non-government organizations also benefit from the increased situational awareness leading to better estimates of resource needs and where to prioritize allocation of resources.

5.6 Conclusion

Social media provides an opportunity to leverage millions of citizen-sensors to increase situational awareness during emergencies and disasters (Goodchild, 2007a). Castillo et al.'s (2013) recent advances in predicting credibility in social media during emergencies introduces a method for determining the veracity of messages during a crisis. Crooks et al.'s (2013) improvements to data mining techniques provide a method for harvesting citizen sensor data to identify and localize the incident areas. Further research on harvesting social media, determining the credibility of messages, and calculating incident areas will enhance efforts to provide real time risk modeling during no-notice emergencies. Further development of these concepts will lead to increased credibility and situational awareness for emergency personnel and citizens. These efforts will be especially beneficial in countries with limited resources to notify citizens during no-notice emergencies using mobile phones.

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Curriculum Vitae

Chris Oxendine is a proud member of the Lumbee tribe and originally from Pembroke, North Carolina. In 1991, Chris graduated from Purnell Swett High School and entered the United States Military Academy Preparatory School. In 1992, he entered the United States Military Academy (USMA) at West Point. In 1996, Chris graduated with a B.S. in Mapping, Charting, and Geodesy and was commissioned as a Second Lieutenant in the U.S. Army. Chris served for over ten years as a Military Police Officer, serving as a company commander, Department of Public Safety Operations Officer, and Special Reaction Team Officer in Charge. Chris also served for over six years as a Space Operations Officer. Chris deployed twice in support of Operation Enduring Freedom from 2008-2009, and in 2010.

In 2001, Chris completed a Master of Arts in Business and Organizational Security from Webster University. In 2004, Chris graduated with a Master of Science in Cartography/GIS at the University of Wisconsin-Madison. From 2004 -2007 Chris taught in the Geospatial Information Science Program, Department of Geography and Environmental Engineering at West Point, NY. During the three year assignment, he taught EV203 Physical Geography, EV378 Cartography and EV379 Photogrammetry. He completed the Master Teacher Program from the USMA Center for Teaching Excellence. He presented his research in four conference proceedings and was invited to present his research twice at the Institute of National Security Studies (U.S. Air Force Academy). Finally, he received four grants (totalling over $17,000). In 2006, he was promoted to Assistant Professor, Department of Geography and Environmental Engineering. Chris entered the PhD Program in Geography and GeoInformation Sciences at George Mason University in 2010. Chris is a Sequoyah Fellow with the American Indian Science and Engineering Society, a member of the Association of American Geographers, and Gamma Theta Upsilon.

Chris is a candidate for the PhD degree in Earth Systems and GeoInformation Sciences from George Mason University in May 2013.