EXPLORING VOLUNTEERED GEOGRAPHIC INFORMATION (VGI) FOR EMERGENCY MANAGEMENT: TOWARD A WIKI GIS FRAMEWORK

A Dissertation

by

CHEN XU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2010

Major Subject: Geography

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Approved by:

Chair of Committee,	Daniel Z. Sui
Committee Members,	Robert S. Bednarz
	Anthony M. Filippi
	Samuel D. Brody
Head of Department,	Douglas J. Sherman

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ABSTRACT

Exploring Volunteered Geographic Information (VGI) for Emergency Management:
Toward a Wiki GIS Framework. (August 2010)
Chen Xu, B.S., Sichuan University;
M.S., Sam Houston State University
Chair of Advisory Committee: Daniel Z. Sui

The past three years have witnessed unprecedented growth of user-generated volunteered geographic information (VGI) on the Web. Although scholars, decision makers, and citizens have recognized the potential value of VGI in emergency management, there exists no rigorous study on the availability, quality, and feasibility of VGI for applications related to emergency management. This dissertation applies methodologies of GIScience and computer science to present an overview of VGI and explore its value in emergency management with the goal of developing a wiki GIS approach for community emergency preparedness.

This dissertation research concludes that VGI and wiki GIS represent new development in public participation in the production and use of geographic information. In emergency management, VGI and wiki GIS suggest a new approach to incorporate the general public in emergency response activities. By incorporating VGI in emergency management, official agencies and the general public gain better situational awareness in emergency management.

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CHAPTER I

INTRODUCTION

1.1. Overview

We are entering an age that grassroots geospatial information is abundant and grassroots mapping is popular. The proliferation of commercial devices capable of receiving positional information from the Global Positioning System (GPS) is the first factor that contributes to the abundance of geospatial information. The second factor is the development of mirror worlds technologies that create digital representations of the earth surface in virtual cyberspace and dramatically lower the difficulty of mapping. Examples of mirror worlds are Google Maps/Earth, Microsoft Bing Maps, and NASA's World Winds. We can record cycling routes with GPS-enabled devices and share tracks with friends on websites, such as Bikely[1]. We can plan next hiking in Google Earth by turning on a layer that collects many of them with detailed information that help hikers plan their trips, and send planed routes to GPS-enabled gadgets. Many of the tracks, of course, are contributed by other hikers. In all of these examples geographic information is collected by grassroots people and maps are produced to serve mapping requirements in grassroots people's daily lives. Besides GPS tracks and maps, grassroots geographic information may be encountered in the form of text such as in travel blogs, in the form of photos, or in the form of videos. Generally, these kinds of information are not collected

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This dissertation follows the style of Annals of the Association of American Geographers.

[1] http://www.bikely.com/

by official agencies, which makes them valuable to enrich our understandings of the earth surface. Collectively and loosely, the emerging kinds of geospatial information are termed *volunteered geographic information* (VGI) (Goodchild 2007). Because of its potential usefulness for engaging citizens in so many diverse applications – from geographic data collection, to environmental monitoring, to urban planning, and of course, emergency management – we are in great need to develop understandings of VGI, about its contents, about its producers, and about its quality.

This study is about the VGI that is available for one particular application, that of engaging citizens in emergency management. It explores the VGI realm for answers to the following questions: what have been systematically produced by volunteers, who are the producers of these kinds of VGI, and what is the quality of VGI? At the same time, it looks for the constraints that may exist to VGI's more effective and wider utilization in emergency management. It is a general consensus within the research community that a successful response to any disaster, natural or human-induced, starts with updated and accurate maps (FGDC 2001; NRC 2007). The experience of recent Haiti earthquake has shown that where updated and accurate maps are not available, VGI can be an effective means to quickly assemble volunteers on a large scale to systematically generate maps for guiding emergency response teams' field work. Haiti earthquake is the first time VGI is purposely implemented for assisting emergency management. Many new tools are developed, and existing web services are improvised for organizing operations. This study examines the consequence of utilizing VGI for engaging citizens in Haitian emergency tasks. Based on the discoveries, it makes suggestions toward a formal framework that integrating VGI with existing emergency management framework. To be useful during emergency management, VGI must be recognized by official agencies, and be part of the existing official framework.

1.2. The Rising of VGI in Emergency Management

The utilizing of VGI for assisting emergency management can trace back as early as in the Hurricane Katrina disaster in 2005. Firstly, VGI is a new mechanism of distributing emergency information through the Internet. Websites take a new role as hub of crisis information. Blogs, wikis, and Google Maps mashups were created by volunteers to assist displaced citizens find shelters or families (Palen and Liu 2007). Blogs, such as Katrina Aftermath[2], are established to share personal stories, images, family information among survivors. At the same time, many of these websites work as non-official information hubs for publishing information related to relief resources. Many personal appeals by the victims are made to the general public through these blogs. Besides blogs, mirror-worlds tools, such as Google Maps/Earth, are widely used for emergency information seeking and publishing purposes. The stories are covered by articles from three major news agencies (Ewalt 2005; Hafner 2005; Thompson 2005). People used Google Maps/Earth to collect and distribute information about the disaster. Some of these examples can be found at this blog[3].

The improvisation of blogs and web-based mapping tools for emergency information distribution can be found almost in every major disaster after 2005. As today’s web-based information searches are done via search engines, next tables show

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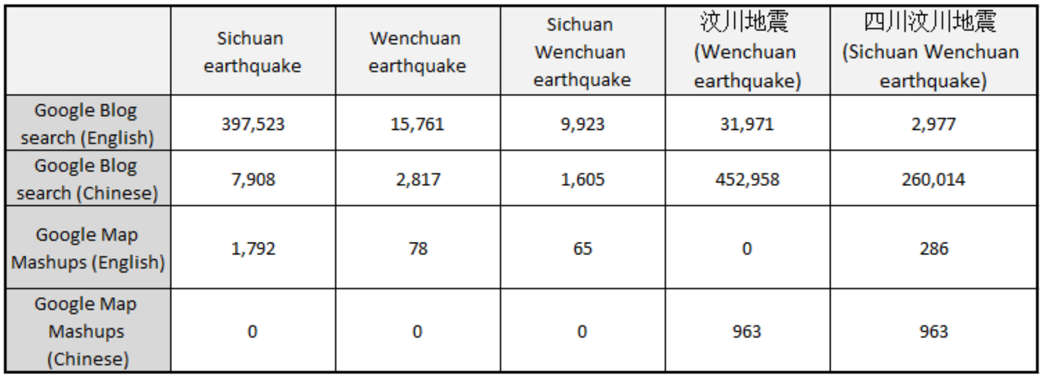
[2] http://katrina05.blogspot.com/

[3] http://googlemapsmania.blogspot.com/2005/09/summary-of-all-known-google-maps.html

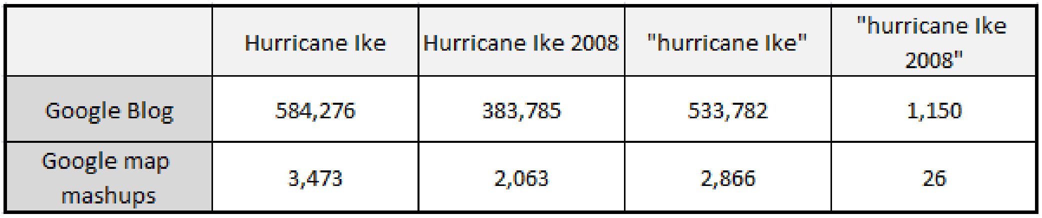
results using Google search engine by keywords match. Table 1 shows results related to Sichuan earthquake 2008, and Table 2 presents results of the Hurricane Ike 2008.

Table 1. Search results for blogs and map mashups for Sichuan earthquake as of 08/16/2008.



	Sichuan earthquake	Wenchuan earthquake	Sichuan Wenchuan earthquake	汶川地震 (Wenchuan earthquake)	四川汶川地震 (Sichuan Wenchuan earthquake)
Google Blog search (English)	397,523	15,761	9,923	31,971	2,977
Google Blog search (Chinese)	7,908	2,817	1,605	452,958	260,014
Google Map Mashups (English)	1,792	78	65	0	286
Google Map Mashups (Chinese)	0	0	0	963	963

Table 2. Search results for blogs and map mashups (for greater Houston area) for the Hurricane Ike as of 09/15/2008.



	Hurricane Ike	Hurricane Ike 2008	"hurricane Ike"	"hurricane Ike 2008"
Google Blog	584,276	383,785	533,782	1,150
Google map mashups	3,473	2,063	2,866	26

These results are coarse and may contain duplicate returns, however they still show the magnitude of the VGI efforts in response to every disasters. Further examine the contents of blogs and map mashups show many information is produced in formats that are new for distributing geographic information, such as photos and videos. These new kinds of information are mostly generated by people who are affected in certain way by disasters, such as a video clip on YouTube showing buildings were shaking during the Sichuan earthquake, or photos on Flickr showing flooded houses on Galveston Island after Hurricane Ike. Aggregation and interpretation of these photos and videos may help acquire unique knowledge about disasters. As illustrated by these examples development in VGI has suggested new solution to engage citizens in emergency management.

Technologies behind VGI are collectively known as web2.0, which is the result of developments in high speed Internet infrastructure, web programming methods, cellular technology, and GPS technology. Most web programming methods for transferring images and videos through Internet were known to computer scientists long before 2005. However low speed Internet made transferring photos and videos less attractive to the general public. Therefore the availability of high speed Internet in people's daily lives is crucial in the development of web2.0 applications. The wide adoption of an information synchronization technology, called Asynchronous JavaScript and XML (Ajax), brings richer and seamless Internet interactive experience to web users. The traditional 'click then wait for a page refresh' pattern has been changed to direct interactions between users and web contents. All data exchange tasks have been delegated to the Ajax engine. The new technologies dramatically closed the gap for user experience between desktop-based applications and web-based applications. The implementation of Ajax in web-based mapping has revolutionized the way geographic information services are provided to the general public, together with development in global positioning technology, they have started a new era of Web Mapping 2.0 (Haklay, Singleton et al. 2008). Examples of web mapping 2.0 applications are:

- OpenStreetMap[4]: OpenStreetMap (OSM) collects grassroots contributions to create a freely available, editable digital map of the world. Mapping, which was once a highly centralized activity which required expensive equipment and trained cartographers, now becomes the hobby of many amateurs, who have little or no formal cartographic training. These amateurs function by using simple and inexpensive positioning devices (e.g. GPS or Wi-Fi signals) which often cost less than $100 and are embedded in many portable gadgets. Over 50,000 volunteers have contributed to OpenStreetMap as of August 2008, and the collected geographic information is fairly accurate (Haklay 2008).

- Wikimapia[5]: Wikimapia harnesses efforts from volunteers to “describe the whole world” (the website mantra) by integrating a wiki system with Google Map services to enable users to identify and describe Earth-surface features. While gazetteer information is limited to name, feature type, and location, most entries on Wikimapia offer richer descriptions, and may provide links to external resources for more detailed information. To date nearly 8,000,000 features have been described, which is beyond the number of entries of the largest extant gazetteer. In recent decades, high costs have caused dwindling augmentation and maintenance of authoritative gazetteers, where Wikimapia offers a viable substitute.

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[4] www.OpenStreetMap.org

[5] www.Wikimapia.org

- Geocommons[6]: Geocommons adds geo-visual analytics to web-based maps, and put simple spatial analytic capacity in the hand of any laypeople. The procedure of designing a map is greatly simplified to uploading data, selecting attribute for mapping, choosing proper data classification scheme, and deciding map style. At the same time Geocommons become a geographic information portal, where users share their maps as well as data. Geographic data are retrieved from either public sources or created by users. All geographic data and maps are shared under the Creative Commons license.

The application that has the most influence is OSM. OSM was funded by Steve Coast in 2004 for the purpose of creating a free editable map of the world. The primary way of collecting geospatial data for OSM is by using GPS devices. Other data resources for OSM include aerial photography, public domain data, or data from local knowledge. Through OSM, mapping which was once a highly centralized activity which required expensive equipment and skilled cartographers, now becomes a hobby of many amateurs, who have little or no formal training in cartography. By aggregating efforts from enormous amount of volunteers, OSM has become the most influential grassroots-driven mapping application. The operation mechanism for OSM, as well as for many other web mapping 2.0 applications, is called crowdsourcing. Crowdsourcing is a neologism coined by Howe (2006). Originally it refers to an emerging business model which makes open calls to undefined masses to accomplish tasks that traditionally performed by employees or contractors (outsourcing) (Howe 2008). Shirky (2008) generalizes the arguments, and asserts that the same model can be effective to reshape the operation of general traditional

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[6] www.geocommons.com

organizations. OSM adopts the crowdsourcing model, by which people act voluntarily and collectively without central coordination, and changes the traditional ways of geographic data collection. This has significant meaning for many humanitarian actions.

While in many developed countries OSM is a tool for recreational purposes, in many developing countries it is a weapon for humanitarian actions. The ability to integrate data from various sources makes OSM ideal for collaborative mapping, especially for developing countries where updated base-map data are often scarce. So far, OSM has been implemented in fourteen countries and regions. In Gaza Palestine, OSM created maps for humanitarian relief actions. In Iran, OSM maps are used for support protections after Iranian presidential election in 2009. After 2010 Haiti earthquake, one immediate challenge is Haiti lacks updated base-maps for carrying out relief activities. In a short time, a large group of volunteers are assembled on the task of creating a base-map for Haiti, and quickly such a map is distributed for guiding fieldworks. By collecting GPS tracks from local volunteers, extracting data from high-resolutions aerial photography, or integrating existing public data, OSM created free, open and updated maps without any centralized planning and organization. This is because OSM is based on a framework called wiki.

A wiki is a server-side hypertext authoring tool that harnesses asynchronous, collaborative effort from a group of undefined participants to create *artifacts of lasting value* (Cosley, Frankowski et al. 2006). The most famous example is the online encyclopedia Wikipedia[7]. As of early October 2009, Wikipedia had 75,000 active

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[7] http://www.wikipedia.org/

contributors and approximately 13 million of articles in more than 260 kinds of languages with about 65 million visitors worldwide visiting Wikipedia monthly[8].

Yochai Benkler views Wikipedia as an example of commons-based peer production system, a new modality of collaboration, which is '*radically decentralized, collaborative, and non-propriety; based on sharing resources and outputs among widely distributed, loosely connected individuals who cooperate with each other without relying on either market signals or managerial commands*' (Benkler 2006). OSM follow the same collaboration model to collect map data from enormous amount of grassroots users. While wiki is an effective tool for authoring and mapping activities, it is also a system for collaboration purposes. Projects, such as OSM, have setup their wiki sites for announcing requirements to users, for tracking progress of projects, and for registering resources. Hence, wiki is a hub that connects volunteers with the final products. In response to the Haiti earthquake, the implementations of VGI, such as OSM road maps, and its corresponding web-based tools, like OSM and OSM Wiki, make significant contributions. It is the first time VGI and its volunteers are systematically deployed for large-scale emergency relief actions. Stories about OSM and several other open projects in Haiti are reported by major news agencies, such as the Guardian (Keegan 2010), the Wired (Hodge 2010), and the New York Times (Giridharadas 2010). A systematic study of VGI experience in Haiti will contribute to the understanding of this new phenomenon, and help develop VGI as an effective tool for future emergency management actions.

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[8] According to http://en.wikipedia.org/wiki/Wikipedia:About

1.3. The Purposes of Study

Haiti earthquake occurred at 16:53 local time on January 12, 2010. The epicenter located 16 miles west of Haiti's capital, Port-au-Prince (PaP). The magnitude of the earthquake is 7.0 Mw. From the very beginning of the emergency relief phase for Haiti, the OSM community participated the humanitarian relief actions and generated maps that were urgently required by field work teams. A wiki site for the OSM project[9] in Haiti has been established by the Humanitarian OSM Team to record key events, to register resources, and to coordinate activities of different groups and individuals.

At the same time another wiki site has been setup by the Crisis Commons project[10] for sharing information among NGOs, citizen volunteers, humanitarian relief agencies, and many other organizations that are involved in Haiti relief actions. In this study records on both wiki sites are studied for the purpose of tracing information flow among different organizations across different geographic regions. The information being focused is VGI. The results will help answer questions like: what VGI is created by whom? How VGI is produced? What organizations or citizen volunteers are involved in the procedure? What is quality of VGI? and What factors influence the VGI quality? By providing answers to the above questions I expect to improve effective implementation of VGI in future emergency management, and make suggestions on a GIS framework that help connect VGI to the existing official geospatial framework.

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[9] http://wiki.openstreetmap.org/wiki/WikiProject_Haiti

[10] http://wiki.crisiscommons.org/wiki/Main_Page

Before going to the details of this study, a synoptic view of VGI applications in Haiti is given to help make a background of this study.

- Before the earthquake, United Nations and Doctors without Borders are carrying out humanitarian operations in Haiti. MINUSTAH is UN’s stabilization mission in Haiti. MINUSTAH has produced maps and geospatial data of Haiti, after the earthquake, permission is granted by the MINUSTAH to OSM to use its data for mapping. Shapefiles based on MINUSTAH data are available on Geocommons.

- Google makes aerial imagery taken by GeoEye public for humanitarian activities in Haiti. Google Map mashup is quickly made for the public to perceive damages made by the earthquake. At the same time OSM volunteers are using the imagery to map spontaneous camps of earthquake victims.

- More remote sensing imageries are available for the public who wish to help in relief actions. Imageries come from several countries’ institutions, international organizations, and companies. OSM community uses these imageries to extract data of collapse buildings, spontaneous camps, and road systems. At the end of January more than 600 volunteers contribute to OSM Haiti; 24,000 features have been mapped; and more than 40,000 road features are mapped. Such data are turned into maps that can be uploaded to Garmin GPS for field works.

- Volunteers are organized in the form of Crisis Camps, where citizens can meet and collaborate on crisis relief projects. From January 16th to March 7th, 28 crisis camps are organized in 17 cities of 5 countries. Volunteers work on projects like collecting RSS feeds, GIS data translation, tool developments and produce OSM data.

- Project 4636 and Ushahidi are established several days after the earthquake. Haitians send emergency SMS to the number 4636, and the information is relayed to corresponding organizations to provide aids to senders. Many messages are in Haitian official language: French and Creole. Those messages must be translated before future process. The work of translation and categorization is given to volunteers organized by two web2.0 startups: CrowdFlower and Samasource. Project 4636 provides a system that is very similar to the 911 system in US, to which people can send emergency message for help. Ushahidi is an open source mapping system for visualizing emergency information. Part of the SMS send to project 4636 are georeferenced and mapped using open web mapping services.

In order to learn from VGI actions in Haiti earthquake and provide answers to previous questions, three objectives are designed:

1. Develop approaches for harvesting and retrieving VGI related to Haiti earthquake. VGI related to other emergency management operations is collected for studying VGI development.

2. VGI, especially OSM, quality is studied to understand what factors affect VGI quality.

3. Based on results from objectives 1 and 2, suggestions are made for a wiki GIS framework that improves VGI's effective implementations in future disaster relief activities.

The dissertation is structured as follows. Chapter II provides literature reviews that help reveal significance of VGI in emergency management, and offer background knowledge about methodologies that are implemented for studying VGI. Chapter III describes methods for data collection, data process, and data analysis in detail. Chapter IV summarizes finding and results of VGI actions in emergency management, especially in Haiti earthquake. Finally, Chapter V makes conclusions about this study and offers some thoughts for future study.

So far to our knowledge, this is the first empirically based study about using VGI in emergency management. For the recognized deficiency of collaboration capability for conventional centralized authoritative based GIS to support extensive interactions between different stakeholders of emergency management, opportunities appear for changing the situation by integrating wiki GIS into existent system structure, and synthesizing VGI as complementary data sources for conventional geographic information. Our research will explore the potential of VGI for emergency management, and develop a viable model for realizing such potential.

At the same time the evaluation of VGI quality will help consolidate VGI as complementary geographic information for satisfying spatial data needs of grassroots users. By facilitating the ability of local communities to serve as first respondents to emergencies, their observations will help build timely assessments of emergency situations. By synthesizing these new kinds of geographic information with traditional GI, our research will help improve situational awareness and provide empirical support on the concept of humans/people as sensors in the context of emergency management.

CHAPTER II

LITERATURE REVIEW

2.1. Introduction

Emergency management, in general, is concerned with natural or manmade events which impact many people (Bumgarner 2008). Disasters have an obvious physical side; people get hurt, lose their properties even their lives. Disasters have another equally devastating facet that is more obscured. Disasters are claimed to be social constructions (Burke 2007). Quarantelli’s (1989) sociological perspective on disasters casts new light on emergency management. Disasters affect society mentally and emotionally (Bumgarner 2008). It is argued disasters are a manifestation of vulnerabilities in modern society; while society grows complex, its conflicts with nature may produce unintended consequences (Canton 2007). Among many other examples Hurricane Katrina in August 2005 illustrates the tragic outcomes of human’s trying to control nature. Failures in the response to Hurricane Katrina exemplify the intricacy of modern emergency management. Hurricane Katrina is the most destructive and expensive natural disaster in American history (White House 2006). The failures in Hurricane Katrina are generally cited as government-policy failures (Sobel and Leeson 2006; Col 2007; Birkland and Waterman 2008). This image of total failures is reinforced by the continuous (24/7) TV coverage (Dynes and Rodríguez 2007; Birkland and Waterman 2008). Even some successful stories of government’s response to the disaster are buried under the image of total government collapse. The pre-storm evacuation and the following search and rescue operation represent the largest and most extensive emergency-management task in U.S.

history (Derthick 2007). Hurricane Katrina reveals a fact that present emergency management is inadequate to cope with large-scale disasters or catastrophes like Hurricane Katrina (Canton 2007). Started from 1940s and 1950s, the emergency-management sector in the United States has gradually accepted a more collaborative approach. By the 1990s, the emergency managers generally adopt a culture of open communication and broad collaboration (Waugh Jr. and Streib 2006). Nevertheless, after 9/11 and Hurricane Katrina there have been strong pressures to reinstate and intensify the command-and-control approach. At the community level, where emergency management is more about restoring public welfare, health, and common ties for community, the performance of an authority-oriented approach is weak (Wenger, Quarantelli et al. 1990). My goal is to demonstrate that a broadened collaborative approach, which incorporates local citizens, is more appropriate for emergency management. The developments in web technologies and public participation model have created momentum for a new community-based emergency management.

I focus on the seldom envisioned group in emergency management – local communities. Based on the false assumptions, local communities are excluded from the realm of emergency management. There were attempts to incorporate public into the procedures of planning and management, but the introduction of such scheme is rather problematic (Barnes, Newman et al. 2007). The development of technologies and participation mechanism restricted the public from participation. Recent developments in web technologies and public participation model are about to lift those restrictions. Traditional emergency management is based on the presumption of social chaos after disaster impact (Dynes 1994). Thus the priority of disaster response should be given to restore and maintain social order with forces from outside (Dynes 2000). In Hurricane Katrina troops were deployed to restore law and order instead of providing relief services. Consequently emergency management for local communities takes a paramilitary command-and-control approach, which emphasizes power and expertise of emergency management personnel to deliver information and service to victims (Scanlon 1982; Quarantelli 1988). Conventional wisdom or disaster mythology holds that local citizens are not to be trusted; they are either paralyzed by disasters or loot, riot, and rob other people (Dynes and Quarantelli 1976; Perry 1983). However, empirical studies contradict such assumptions (Dynes and Quarantelli 1976; Quarantelli and Dynes 1985; Goltz, Russell et al. 1992; Perry and Lindell 2003). Indeed, even people are shocked by the initial impacts that status lasts only for a short period. More often people assess the situation for best solutions to cope with an emergency (Grinker and Spiegel 1945). Behaviors after disasters are generally pro-social and rational. Actually local community is among the first forces to start disaster recovery operations.

After the failures in Hurricane Katrina, the limitations of present emergency management in dealing with large-scale disasters or catastrophes are obvious (Quarantelli 2006). Canton (2007) and Col (2007) argue a community-level management system supported by state and federal resources are essential to cope with catastrophes. Command-and-control should be replaced by coordination in a system consisting of non-paramilitary government agencies, Non-governmental organizations (NGOs) and local communities, and government assumes the role of an arbitrator. The shift of emergency management paradigm raises serious challenges for present management culture as well as techniques. It is a general consensus within the research community that a successful response to disasters starts with updated and accurate maps (FGDC 2001; NRC 2007). Geospatial technologies in general and geographic information systems (GIS) in particular have played crucial roles in producing these maps (MacFarlane 2005; van Oosterom, Zlatanova et al. 2005). Although most data, information, and knowledge in emergency decision-making are geospatial in nature, present GIS is incapable of collecting, analyzing, and communicating time-critical information during disasters (Zerger and Smith 2003). Several suggestions are made (Cutter 2003), and in summary two fundamental transforms are called for a GIS aid system for emergency management. Firstly, the operation of GIS transfers from computer modalities to human modalities (Cai, Sharma et al. 2006). Secondly, the paradigm of GIS converts from place-based to people-based (Miller 2007).

The developments in web technologies, cellular technologies, and geographic positioning technologies (GPS) have dramatically changed people's use of internet. All developments are under the banner of 'web2.0'. The diffusion of web2.0 innovations has brought about the explosion of user-generated contents (UGC) available online with explicit geo-location tags. Goodchild (2007) termed the new type of geographic data volunteered geographic information (VGI). The phenomenon is not confined to data alone, but is manifested in hardware, software, and people – a broader process known as the wikification of GIS (Sui 2008). VGI and wiki GIS are a promising path towards lifting constraints on the more effective and wider applications of GIS-enabled pubic participated emergency management at the community level. The primary goal of this chapter is to review present researches and studies on VGI with focus on its potential implementations in emergency management. In doing so, I attempt to demonstrate the uniqueness of VGI in order to show its capability to trigger the transformation of present emergency management towards a holistic approach. In pursuance of the goal, I review researches on emergency management to give a synoptic view on the inadequacy of present system for community-level emergency management in sub-section 2. In sub-section 3 studies on VGI are surveyed to illustrate that the unique characteristics of VGI and the wiki mechanism are the power of web2.0 to enable an effective geocollaboration system for emergency management at the community-level. Then in sub-section 4 I attempt to introduce cybernetic space and maps as wikis as two pillars for a wiki GIS conceptual framework, whose system thinking views people, software and environments as an integral whole. Finally, sub-section 5 is summary and conclusion.

2.2. The Inadequacy of Present Emergency Management System

When spoke to the International Conference on Industrial Crisis Management in New York City, Quarantelli (1986) pointed out there is a wide gap between emergency planning and emergency management; and planning is not necessarily transferred into successful management in disasters. Problems would emerge in three aspects: the communication process, the exercise of authority, and the development of coordination. Communication system could be overloaded; the predefined communication procedures might be interrupted by the unforeseen situations; communication among different stakeholders could turn into chaos; the operational chain-of-command could break down; there would be authority or domain conflicts between organizations; lack of consensus on the understanding of ‘coordination’ might lead to the dysfunctional coordination; and the stress during disaster response would strain relationship between organizations. In summary, planning concerns about the general strategies for preparing community for possible emergencies and disasters; emergency management makes tactical decisions based on specific situations, which cannot be fully predicted by planning. In Hurricane Katrina it is inadequate planning and poor execution in almost every aspect mentioned by Quarantelli that lead to the total failures (US House of Representatives 2006; White House 2006; Wise 2006). Hurricane Katrina also signals a major turning point for emergency management in U.S.

In the United States, the functional responsibilities of emergency management generally belong to the state and local governments. Higher level governments intervene when the severity or damage of disasters exceed the capacity of local government. The Federal Emergency Management Agency (FEMA) has increasingly assumed the responsibility of coordinating federal institutions' operations in catastrophes since its establishment in 1979. Scientific institutions at the national level are established to watch the impending disasters and alert local governments. Overall local governments are at the frontier of emergency management in US. The role of local government concerned with disasters consists of comprehensive emergency management and integrated emergency management (Drabek and Hoetmer 1991). Local governments conduct comprehensive management when coordinate activities in four phases of emergency management: mitigation, preparedness, response, and recovery, and perform integrated emergency management when coordinate operations with other entities both laterally and vertically (Col 2007). One of the lessons from Hurricane Katrina is local government must be able to operate decisively and solve the emerging problems from the three aspects effectively. As exposed by the failures in Hurricane Katrina the old emergency management approach adopted by the government is inadequate for large-scale disasters. New solutions are called, which are based on social science knowledge not myths (Quarantelli and Dynes 1972). Two principles are important for the design of a new system: firstly, for disaster plans to be relevant for the operations, they should be developed by those who are affected by and to carry out those plans (Dynes and Drabek 1994); secondly, a resource-based theoretical model rather than authority-based is essential for effective emergency management (Dynes 1994; Neal and Phillips 1995; Quarantelli 1998; Drabek 2003).

The implications of these principles are: coordination rather than command-and-control is paramount for the new paradigm; local communities should be incorporated into the planning stage as well as the management; geospatial technologies are crucial for an effective and efficient system to locate and manage resources. Effective emergency management involves extensive coordinated activities among various organizations through the communication of emergency information (Michael K. Lindell 2007; Homeland Security 2008). A nearly universal phenomenon in the occurrence of disasters is the convergence of people, information, and material into the disaster impacted area (Fritz and Mathewson 1957). Hundreds of organizations have certain relationship with emergency management. The coordination of organizations and activities in the face of sudden large-scale social behavior change is crucial for the new paradigm for emergency management (Hughes, Palen et al. 2008). Unfortunately, ‘coordination’ isn’t a concept of much consensus (Quarantelli 1986). Some organizations see coordination as informing others about their activities, while other organizations regard coordination as the centralization of decision-making among a few core agencies. Although findings from sociology show local communities react actively not passively to disasters, and their activities tend to ‘reduce, deflect and soften’ disastrous aftermath that could be even worse (Dynes and Quarantelli 1976), their roles in the emergency managements are largely ignored by present system (Murphy 2007). The emergency management operates not with, but for the local community (Laughy 1991). Nevertheless the importance of community in emergency management is undeniable.

Disasters occur locally, where the immediate local community often responds first and copes with the situation and its consequences (O'Leary 2004). This makes emergency management a community-level concern (Schafer, Ganoe et al. 2007). Even though plans and policies are established at the state and federal level, the initialization and implementation of them are at local communities; and the delivery of mitigation and relief services begins at the local level (Maskrey 1989; Godschalk, Kaiser et al. 1998). The significance of local community is recognized by the research and academic sector. Not only local communities should be involved in the development of emergency management policies (Lindell and Perry 1992), but should be prioritized in the relationship between upper-level government and local-level community (Quarantelli 1988; Murphy 2007). Emergency management capacity must be built bottom-up, for local communities may have to stand on their own for days (Waugh Jr. and Streib 2006). The essentialness of community involvement in emergency planning and management is gradually recognized by the government (Day 1997). States like Florida and Washington have programs to involve local communities in emergency mitigation (Godschalk, Brody et al. 2003). After 9/11 FEMA started to provide seed funding to help local communities develop citizens’ emergency response team. However, it is proved a daunting challenge to provoke public interest in disaster relevant decision-making (Williams, Suen et al.

2001; Burby 2003). We need imagination to encourage public participation. The first step is to improve government transparency through information sharing (Arnstein 1969). Information is the catalyst for collaboration and coordination (Noveck 2009).

The public’s right to information forms a cornerstone to democracy. Information is crucial for community emergency management. Once access to information public can make informed decisions to reduce their vulnerability (International Federation of Red Cross and Red Crescent Society 1995). By making government data more accessible to the public, it encourages public deliberation on government policies (Bohman 2000; Roberts 2004). The first wave of public participated planning proliferated in the early 1990s, and by the mid-1990s the enthusiasm about public participated decision-making waned. The method was deemed too costly and time consuming with up to two years delay in some cases. The question is not about if public should participate, but how public participate. The system lacks mechanism to consume public contributed information. In response to disasters, information has been recognized as ‘a vital form of aid in itself … Disaster affected people need information as much as water, food, medicine or shelter. Information can save lives, livelihoods and resources’ (International Federation of Red Cross and Red Crescent Society 2005). As local communities are seen as victims instead of participants in emergency management, they are largely considered as information receivers. However, there is significant discrepancy between the perception of essential emergency information by the government institutions and the perception by the general public (Quarantelli 1986). On the one hand we have gained unprecedented capabilities to disseminate disaster information due to the developments in the Information and Communication Technologies (ICT) sector, on the other hand field surveys report information dearth of disaster affected people (Boyle, Schmierbach et al. 2004; Shkovski, Palen et al. 2008; Sutton, Palen et al. 2008). In response to the information dearth public don't lack imagination and creation. Besides the simplest mouth-to-ear mode communication and phone-based communication, Internet-based communication has quickly become the emergent mode of emergency communication, especially after the burgeoning development of new web programming technologies since 2004.

The new web programming technologies are termed as 'web2.0' by Tim O'Reilly in 2004. Also web2.0 is a term that covers a wide range of emerging web phenomena from 'web as platform', 'crowd wisdom', to 'crowdsourcing'. Its concrete form is a series of interactive web applications such as Facebook[11], Flickr[12], Wikipedia[13], Youtube[14], and Google Maps[15]. These applications enable people act voluntarily and collectively without central coordination. The potential of applying web 2.0 applications to widely incorporate efforts from citizens for research or planning activities has been recognized by researchers (Goodchild 2007; Cuff, Hansen et al. 2008; Dykes, Purves et al. 2008; Gouveia and Fonseca 2008; Sui 2008). In the field of GIScience, researchers' interests are on the web2.0 applications that have a geographic component. The correspondent informational products are termed 'Volunteered Geographic Information (VGI)' by Goodchild (2007). Workshop on the potentials and research questions of VGI was

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[11] http://www.facebook.com/
[12] http://www.flickr.com/
[13] http://www.wikipedia.org/
[14] http://www.youtube.com/
[15] http://maps.google.com/

organized and held in Santa Barbara in 2007[16]. VGI is recognized as a new production mode for geographic data with potential value for more serious applications than entertainment and social networking. The convergence of heterogeneous public information and opinion is through the wiki mechanism. Wiki mechanism naturally supports bottom-up collaboration among participants, who function like sensors (Bishr and Kuhn 2007; Goodchild 2007; Laituri and Kodrich 2008). VGI is valuable for a holistic emergency management which incorporates local communities into the emergency management system. Wiki is a new collaboration mechanism that enables discourse between government institutions and the general public on a scale unimagined before (Noveck 2009).

It is a general consensus within the research community that a successful response to any disaster, natural or human-induced, starts with updated and accurate maps (FGDC 2001; NRC 2007). Geospatial technologies, led by the increasing convergence of geographic information systems (GIS), remote sensing (RS), global positioning systems (GPS), and location-based services (LBS), have played crucial roles in producing these maps (MacFarlane 2005; van Oosterom, Zlatanova et al. 2005). Although geospatial technologies in general and GIS in particular have been used quite extensively in all phases of emergency management (Briggs, Forer et al. 2002; Greene 2002; Thomas, Ertugay et al. 2007), the deficiencies of existing GIS technologies have also been widely recognized (Cutter 2003; Baker, Lachman et al. 2004). The implementation of VGI and wiki GIS in emergency management is a promising path towards lifting several constraints on the more effective and wider applications of GIS in emergency

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[16] http://www.ncgia.ucsb.edu/projects/vgi/

management. The new system aims to empower individual citizens and their non-institutional organizations in local community with geospatial-enabled emergency information thus form a solid foundation for community-based emergency management.

2.3. Web2.0 and VGI in Emergency Management

Contrary to disaster myths, local communities in fact are the ‘first responders’, who act on their own to conduct search and rescue activities or administer first aid (Dynes 1970; Fischer III 1998). Even after the arrival of emergency management personnel, citizens continue to self-organize and provide assistance (Comfort 1999). These organizations that form upon perceptions of needs or problems related with disaster situations are called ‘emergent groups’, which comprise citizens that pursuit collective goals (Stalling and Quarantelli 1985). Emergent groups appear in response to disasters as well as during preparedness and recovery phases of emergency management (1985). Stalling and Quarantelli (1985) investigate and describe these informal groups. In response to disasters, emergent groups act as ‘damage assessment groups’, ‘operation groups’, or ‘coordinating groups’. They tend to comprise a core of continuing members as well as provisional irregular participants. The general organizational structure of emergent groups is flat, and tied closely to the undertaking tasks. Emergent groups exist in non-emergency times too; usually they are upon some potential or existing problems associated with disasters. The informal relationships inside organizations make it easier for people to communicate and create conditions for the group to pursuit collective goals (Lowndes, Pratchett et al. 2006). One suggestion made by Stalling and Quarantelli is that the emergence of emergent groups is unpreventable, therefore the inevitability and pervasiveness of their emergence and behavior should be considered in emergency management.

Naturally local government would be designated to coordinate activities of emergent groups. Experiences from China prove government involvement is crucial to the success of community emergency management (Col 2007). A narrow definition of community is that ‘community consists of persons in social interaction within a geographic area and having one or more additional common ties.’ (Hillery Jr. 1955) Sociologists such as Durkheim and Tönnies characterize those ties as common understanding, shared experiences, or mutuality (Gilchrist 2009). These common ties are crucial to community emergency management. Evacuees’ of Hurricane Katrina expressed their eagerness to return to their communities (Procopio and Procopio 2007). A community consists of citizens, groups, and organizations. The informal networks among them produce the experience of community (Gilchrist 2009). Internet has bred virtual communities whose network connections extend beyond geographic boundaries. The developments of web2.0 technologies further lower the barriers to group action (Shirky 2008). Web2.0 projects the common ties and activities of physical community to the web-based virtual community by creating a virtual space for group collaboration. In this space command-and-control is outdated, and coordination and collaboration are norm (Winerman 2009). VGI as products of group collaboration and wiki as group coordination mechanism are about to change the landscape of emergency management. Citizens involve in emergency management has a long history; Internet and web2.0 only make the image more visible and broaden the scope of public participation. Examples are abundant that web2.0-enabled emergent groups carry out tasks like damage assessment, operation, and coordination in response to disasters.

Few web2.0 applications could arouse more public interest in mapping than Google Maps and its desktop version Google Earth (Butler 2006; Nature 2006). In the field of emergency management, they are convenient tools for communication. In the aftermath of Hurricane Katrina several government institutions used Google Maps to publish flood damage images to the public (Tulloch 2007). Google Maps mashups were created by volunteers to assist displaced citizens find shelters or families (Palen, Hiltz et al. 2007; Scaffidi, Myers et al. 2007). Disaster relief services were coordinated through blogs and forums (Majchrzak, Jarvenpaa et al. 2007). More importantly, web provides a space where displaced evacuees could reconnected with their communities (Procopio and Procopio 2007; Shklovshi, Burke et al. 2008). The same bottom-up and collective activities were widely distributed across China's web communities in 2008 Sichuan earthquake (Winerman 2009). People voluntarily collected and published victim information of their local community on internet forums. Social networking websites, e.g. Tianya[17], and Google Maps were implemented for coordinating disaster relief efforts of NGOs and grassroots volunteers. In 2007 Virginia Tech crisis people used Facebook, Wikipedia and other kind of web2.0 applications to quickly solve the problem of who are the victims even before the university releasing information to the public (Palen 2008). Collectively these volunteers are recognized as the "first responders of the wired world" (Currion 2005). The traditional geographic convergence of people, material and information happens in virtual space as online social convergence (Palen 2008). Most

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[17] http://www.tianya.cn/

activities are spontaneous. GeoChat is an attempt to coordinate those spontaneous activities of citizens with emergency response operations of government institutions and NGOs, which implements the concept of people as sensors (Laituri and Kodrich 2008; Butler 2009). Generally information contributed by citizens is valuable to government decision-making by improve situational awareness (ESRI 2008). With the development in mobile technologies and geo-positioning technologies, users can upload real time field information, which potentially improve the visualization of the extent of the emergency (Scherp, Ireson et al. 2009).

In non-emergence times, citizens access to data is a premise for effective participation in emergency planning and decision making (Onsrud and Craglia 2003). Numerous studies reveal grassroots users have difficulties with gaining access to governmental geospatial data (Leitner, Elwood et al. 2000; Elwood 2006; Elwood 2008). Kang and Cuff (2005) proposed creating a online public sphere, where citizens can produce collaboratively and share freely geographic information in a data commons (Cuff, Hansen et al. 2008). Such a data commons is valuable to the pursuit of science as well as politics (Gouveia and Fonseca 2008; Rinner, Kebler et al. 2008). Two characteristics make VGI potentially beneficial to government geographic data collection tasks too. Firstly, VGI offers new details about the Earth’s surface. Traditionally, remote sensing (RS) has been the primary method for producing geospatial data. Due to the inherent constraints of the technologies (such as satellites orbits and sensor resolutions), geospatial data derived from remote sensing imageries represents only the bird’s eye view of the Earth. At the same time RS is not the profession for environmental information, cultural information, or population information (Goodchild 2007). Photos have already been used to construct a disaster scene in 3-D with free tools (Grifantini 2009). Disaster photos from normal people are abundant on Flickr, which can be used as evidential documents for emergency management agencies' decision-making (Liu, Palen et al. 2008). Non-geospatial data are often collected through direct observations. Temporal and budgetary restrictions often cause incomplete or inaccurate datasets. Citizen science enables individuals to become active participants in collecting and sharing scientific data about their neighborhoods and communities (Paulos, Honicky et al. 2008). Secondly, VGI as a crowdsourcing effort is time-friendly (Howe 2006; Floridi 2009). Investigations of Wikipedia entries show qualities are improved with more volunteers' contributions (Stvilia, Twidale et al. 2005).

The world of geographic information, before web2.0, is dominated by professional experts, who produce geographic information to be consumed by amateurs. It is a top-down, authoritarian, and centrist paradigm (Goodchild 2007). The world of VGI, as described by Goodchild (2007), is chaotic, without formal structures. Amateurs assume the role of geographic information producer as well as consumer. Open and free is norm in this world (Goodchild 2008). Web2.0 technologies have made significant innovations that impact could expand GIS implementations in people's daily life. Software that was once installed on desktop computers, are turned into services. Services like Geocommons[18] make complex geographic data processing and mapping tasks into a fun routine of accidental geographers (Unwin 2005). For years web services have become the industry standard to support interoperability across programming languages, platforms, and operating systems. Different web2.0 services can be synthesized (it is

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[18] http://www.geocommons.com/

called mashup in the web2.0 jargon) to achieve more complicated functions (Miller 2006; Zang, Rosson et al. 2008). A more fundamental change is that data and computing power exist in a ‘Cloud’ (Hudson-Smith, Batty et al. 2008). Resources can be accessed based on requirements of clients (Armbrust, Fox et al. 2009). The four components of conventional GIS – hardware, software, data, and people, have new manifestations as Cloud, service, VGI, and crowds. The phenomenon is described as the wikification of GIS (Sui 2008). Camarero and Iglesias (2009) call the wiki method for emergency management Disaster2.0. Questions about data quality, access control, source credibility, and empowerment are the challenges for the new paradigm for emergency management (Flanagin and Metzger 2008; Goodchild 2008; Goodchild 2008; Sui 2008).

2.4. Emerging Methods for Community Emergency Management

Internet was proved to be reliable communication system in many disasters, when more traditional emergency communication systems like radio and television stations or phone lines went down (Newsom, Herzenberg et al. 1999). Internet enables emergency personnel to communication quickly and effectively, and virtually breaks barriers of race, gender, nationality as well as the geographic limitations, thus more informed decisions can be made; Internet provides excellent resources for disaster researches; and create enhanced environments for emergency educations (Gruntfest and Weber 1998). Although Internet was considered to facilitate two-way communications in emergency management, it is a formidable task to achieve an effective synergy of Internet communication and emergency management (Newsom, Herzenberg et al. 1999; Wybo and Lonka 2002). Emergency information communication is a complex system that consists of various stakeholders. The lack of synergy creates major hurdles for successful emergency management (Quarantelli 1986). The development of web2.0 technologies suggests new solutions to the old challenge.

A Wiki, as defined by Leuf and Cunningham (2001), is ‘a freely expandable collection of interlinked Web pages, a hypertext system for storing and modifying information – a database where each page is easily editable by any user with a forms-capable Web browser client’ (p. 14). For more information on wiki see (Raman 2006). The most famous application of wiki is Wikipedia – a free online encyclopedia. In the government sector the same software for Wikipedia has been implemented for sharing information among intelligence officers (Beizer 2008). It is a pioneer application of web2.0 technologies in the government sector with significant success (Thompson 2006). In the emergency management community, the wiki way is regarded as a promising solution to emergency information communication in a time-critical fashion that leads to multi-organizational collaboration (Raman 2006; White, Plotnick et al. 2008). It is also a way to harness the power of collaboration from citizens (Shneiderman and Preece 2007). The same mechanism can not only be applied for creating and sharing non-geospatial information, but also works for geospatial information. The OpenStreetMap (OSM) project implements the wiki for geographic information. OSM collects citizens’ contributions to create a freely available, editable digital map of the world. Mapping, which was once a highly centralized activity which required expensive equipment and trained cartographers, now becomes hobbies of many amateurs, who have little or no formal cartographic training. These amateurs function by uploading GPS tracks, uploading public domain data (e.g., US Census Bureau TIGER data), annotating aerial photographs (Yahoo! has authorized OSM to use its aerial photographs) or reviewing peers’ contributions. Over 50,000 volunteers have contributed to OSM as of August 2008. Wikis like OSM are palimpsestic in nature. As wiki contents are constantly developed by their users, wiki forms a continuous procedure which is always unfinished. At the same time the conventional relationship between producer and consumer becomes blurred and better be replaced by a produser relationship (Bruns 2008). In order to understand this highly fluid and dynamic process, only focusing on the information perspective of wikis is insufficient; an inclusive conceptual framework is called that considers information as well as the produser communities as an integral whole (Coleman, Georgiadou et al. 2009).

Dodge and Kitchin (2005) suggest a conceptual framework to understand the effects of software on the spatial formation of everyday life. The framework is composed of components like individual software and hardware, the networking of software or hardware, the regulation software for the networks, data exchange between software inside the networks, and the networking of software and hardware networks. Technicity and transduction are the fundamental concepts to the understanding. Technicity refers to the ‘the productive power of technology to make things happen’, and transduction is the process of ‘constant making anew of a domain in reiterative and transformative practices’ (p.162). Software impacts everyday life ‘because its technicity alternatively modulates space through processes of transduction’ (p.162). The space for everyday life, the Euclidean space, is no longer neutral, homogenous and insignificant. Space is the fabric of social existence, formed by the transductive networking of the relationships between subjects, their activities, and their environment (Lefebvre 1991; Dodge and Kitchin 2005). The same argument for a transformed virtual space is hold by Graham (1998) about ‘cyberspace’ created by the convergence of computers and ICT. The notion of one single unified cyberspace is rejected, replaced by a notion of ‘multiple, heterogeneous networks, within which telecommunications and information technologies become closely enrolled with human actors, and with other technologies, into systems of sociotechnical relations across space’ (p.178). See Figure 1 for an illustration of cyberspace. Thus physical space as geography, where everyday life happens, is continuously transformed by actions in virtual space as cyberspace. This transformation opens a new space – cybernetic space (see Figure 2.), a synthetic space of physical space and cyberspace, where the experience of cyberspace is depend on the location in physical space (Mitra and Schwartz 2001; Mitra 2003).

The cybernetic view of space emphasizes that in order to understand the relationships and consequences in the carved-out synthetic space, both cyber and physical components of the cybernetic space need to be understood together (Mitra and Schwartz 2001). With the rapid developments in web2.0 technologies, people have gained more mediums to enter cyberspace, the importance of physical space has become even more obvious. For example, people in order to enter the cyberspace, have to find a place with at least ICT infrastructures and electricity for them to use mobile phones or computers. At the same time, cyberspace affects people’s perceptions about physical space. Location based services (LBS) help produce a sense of ‘familiarity’ even when people are in an ‘unfamiliar’ physical space (Mitra 2000; Radoczky and Gartner 2005). The implication for emergency management is to build a cybernetic community where displaced citizens can maintain their common ties through cyberspace as means to provide necessary comfort when they are in an unfamiliar environment.

The abandonment of a Euclidean view of cybernetic space renders place-based geographic information science insufficient (Graham 1998; Miller 2007). Map as the primary tool of geographers has been seriously challenged by the task of cybernetic space mapping. Since cybernetic space is being continually constructed, map as a representational tool cannot sufficiently visualize the dynamic process. Map should become a medium through which people communicate their actions in a cybernetic space; hence map is an ongoing process as ‘mapping’. As web2.0 bring highly personalized cyberspace to individuals, the resulting cybernetic space has likewise become personalized. Consequently, cybernetic space mapping is a personal framework for knowledge about the world, and a set of personal assertions about the world itself (Kitchin, Perkins et al. 2009). There are then personal values and judgments contained in the maps (Kitchin, Perkins et al. 2009). The meaning of mapping then depends not only on geometric forms, contents and technologies, but also on culture and politics (Perkins 2009).

The convergence of heterogeneous personal mapping is through a wiki – maps as wikis. Examples like Wikipedia and OSM have proven wiki is a promising way to harness collaborations from crowds. Therefore a wiki GIS for community emergency management is a wiki-based mapping system. There is not only expert knowledge, but also personal experiences and observations in this system. Key to a success system depends on the effective synthesizing of heterogeneous information. Equally important is a system able to support personal mapping in cybernetic space. Accordingly, a wiki GIS is a two level system which has a personal component and a common component. The interaction of two components is through feedback. As a whole a wiki GIS is to collect and share emergency knowledge among communities, therefore create more resilient communities.

2.5. Summary of Problems

After the failures in Hurricane Katrina, the limitations of present emergency management in dealing with large-scale disasters or catastrophes are obvious. There are strong pressures to intensive the common-and-control approach in emergency management. However sociology studies have shown that a bottom-up collaboration approach, which involves local citizens, is more appropriate for emergency management at the community level. The first step towards a citizen involved emergency management is to improve government transparency through information sharing. Information is the catalyst for collaboration and coordination. But, previous experiences show an effective mechanism for citizen involvement is equally important. The developments in ICT and web2.0 technologies suggest new a new mechanism for public participation. The increasing penetration of ICT makes Internet more accessible to everyday life, and web2.0 enables more personalized Internet experience. VGI and wiki as two phenomena of web2.0 have significant implications for community emergency management. VGI is a possible solution to information dearth as well as a complementary resource for government emergency information. Wiki is an effective way for synthesizing heterogeneous information. Both VGI and wiki are highly fluid and dynamic phenomena. Only focusing on the information perspective is insufficient for providing comprehensive understanding. The produser communities must be brought into study. To understand VGI and wiki is to understand produsers' actions in both cyberspace and physical space. While physical space can limit access to cyberspace, cyberspace can influence perceptions about physical space; consequently, VGI, wiki and produsers cannot be studied in two separate spaces. The synthesis of the two space opens a third space as cybernetic space, where the experience of cyberspace is depend on the location in physical space. A wiki GIS framework for community emergency management is a framework for cybernetic space mapping. Map is no longer only a representational tool, but a medium for communication, a procedure as mapping. Personal mapping in cybernetic space is synthesized via wiki mechanism. Maps-as-wikis is a promising path towards more effective and wider applications of geographic information technologies in emergency management.

Although scholars, decision makers, and citizens have recognized the potential value of VGI in emergency management, there exists no rigorous study on the availability, quality, and feasibility of VGI for applications related to emergency management. This dissertation applies methodologies of GIScience and computer science to present an overview of VGI and explore its value in emergency management with the goal of developing a wiki GIS approach for community emergency preparedness.

CHAPTER III

METHODOLOGY

3.1. Overview

This chapter explains methods and tools used in this study. Since VGI is non-traditional geographic information, some corresponding methods and tools are new for traditional geographic information science, especially for data exploration, collection, and processing. These methods and tools are developed by computer science researchers and are modified for the purposes of this study. Since VGI is a bottom-up process, data exploration is crucial for discovering the most important data. Data-exploration methods are discussed in the next sub-section. In sub-section 3.3 data-processing methods are described for both spatial and non-spatial VGI. Visualization techniques are implemented to study interactivities among volunteers, and are introduced in the final sub-section.

3.2. VGI Exploration

In his describing about the world of VGI, Goodchild (2007) lists the following examples: Wikimapia, which is a wiki gazetteer; Flickr, which is a photo sharing website; MissPronouncer, which helps correct place-names’ pronunciations; OpenStreetMap, which lets volunteers collaboratively draw maps about the world; and countless map mashups on Google Maps. Internet is the new development frontier for geographic information. Web-based VGI can potentially change the implementation of geographic information in people’s daily life. In the field of emergency management, a discovery by recent studies is the traditional geographic convergence of people, material and information happens in virtual space as online social convergence (Palen 2008). People converge via online information communication enabled by various web2.0 technologies. The voluntary uses of internet to coordinate grassroots involvements in emergency situations have been noticed and recorded by researchers from disciplines like geographic information science, computer science, and social science. As early as in 2007, blogs, message boards, and wiki sites were implemented for publishing information about shelter locations, family tracing, and missing persons during the Indian Ocean tsunami and Hurricane Katrina (Laituri and Kodrich 2008). In the same year, during the Virginia Tech crisis grassroots web users used Facebook, Wikipedia and several other web2.0 applications to piece together the victim names (Palen 2008). The exploration of emergency information during major disasters becomes a trend that has been detected by tools like Google Trends[19]. During 2008 Sichuan Earthquake, 2008 Hurricane Ike, 2009 California Wildfires, and 2010 Haiti Earthquake, Google Trends shows spikes in keywords searches on emergency information. Real time search engine like Crowdeye[20] is another way to visualize the magnitude of web contents increase, which are related to a major disaster. Many spatial information related tasks, such as in emergency management, inherently incorporate multiple information resources and people, and are dependent upon unique domain knowledge and expertise. VGI is an approach for stimulating large-scale collaboration and data sharing among general web users with various expertise towards a common goal. As VGI is seldom collected in a controlled manner, effort must be made on the pertinent aspects of it gathered from various sources. For spatial and non-spatial geographic information different methods are required for proper information aggregation, and classification.

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[19] http://www.google.com/trends

[20] http://www.crowdeye.com/home.aspx

Spatial Information

OpenStreetMap (OSM) collects grassroots contributions to create a freely available, editable digital map of the world. Mapping, which was once a highly centralized activity which required expensive equipment and trained cartographers, now becomes the hobby of many amateurs, who have little or no formal cartographic training. These amateurs function by uploading GPS tracks, uploading public domain data (e.g., US Census Bureau TIGER data), or annotating aerial photographs (Yahoo! has authorized OSM to use its aerial photographs). Over 50,000 volunteers have contributed to OSM as of August 2008, and the collected geographic information is fairly accurate for London and the rest of England (Haklay 2008). In Europe where geographic information is expensive, OSM offers free access to up-to-date geographic information. In the United States, where public domain geographic information is relatively abundant, OSM help enrich those datasets with more details (e.g., adding landmarks information). Where the cost prevents public mapping agencies to frequently update geographic data, OSM through crowdsourcing suggests solutions to follow rapid changes. Figure 1 shows monthly contributions to the OSM for Houston metropolitan area in 2009.

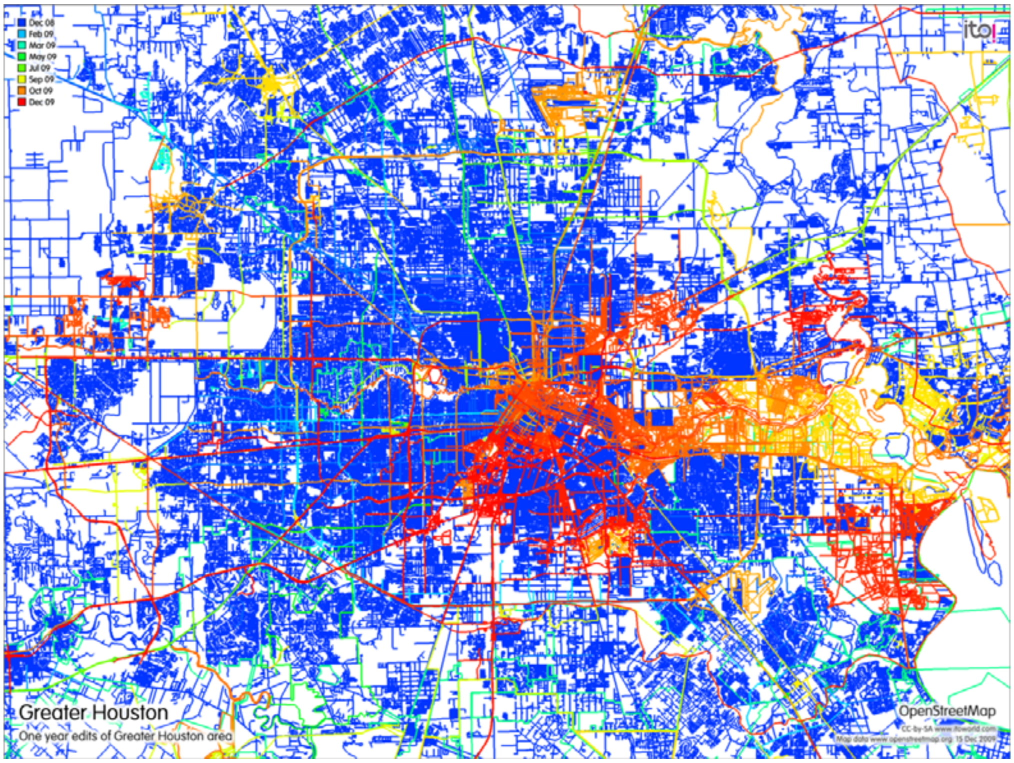

Figure 1. Monthly contributions to the OSM Houston Map by volunteers.

OSM uses various data sources for generating OSM geographic information. Originally, OSM uses GPS tracklog as source. Later, capability to generate information using satellite imagery has been added to the OSM platform. The most popular source for imagery is Yahoo! Maps after an agreement has been made between Yahoo! and OSM. Other satellite imageries can be used as data sources, if they are in the public domain. These include Landsat and imageries donated by private companies, for example, in the Haiti Earthquake Google, GeoEye, and DigitalGlobe gave many high resolution imageries to the OSM community. While manpower is required to create OSM data by tracing either GPS tracklog or satellite imageries, OSM data can be produced by using programs to automatically replicate geographic data in public domain, such as TIGER data. Generally, data that their copyrights conform to the OSM license can be integrated into the OSM system. OSM has designed a highly flexible data model to accommodate data with huge differences. The OSM data model is topological, and is quite different from the traditional GIS data model. The basic components of OSM data model are *nodes*, *segments*, and *ways*.

- Nodes are points with coordinates;
- Segments are a directed connection between two nodes;
- Ways are an ordered list of segments.

Only nodes and ways are assigned tags to denote feature types, e.g., road, railroad, or lake. To define a tag is open and without restrictions. Individuals can define their own tags. Tags are used for rendering OSM features, therefore using recommended tags help render features correctly.

OSM data are open to registered users for editing such as correcting errors, adding attribute values, or deleting features. Figure 2 represents the common processing procedure.

Figure 2. The OSM data creating procedure.

There are two ways to access OSM data either via a service interface or through data export function. Like many web2.0 applications, OSM data can be accessed as a service via an application programming interface (API).OSM data can also be exported as images or raw data. Since OSM licenses data under the Creative Commons Attribution-ShareAlike 2.0 license, its data can be freely used by third-party users only if they license their derivative products under the same license. CloudMade[21] is one of those third-party users of OSM data. Build its services upon OSM data, CloudMade contributes advanced mapping and location-based service (LBS) functions to the OSM community. At the same CloudMade allows users to download OSM data from its servers. Although data can be exported from the OSM website, they are in a unique XML-based format which is not widely supported by most desktop GIS yet. This prevents the implementation of OSM data in traditional GIS applications. CloudMade converts raw OSM data to shapefile format which greatly eases difficulty of OSM data usage in traditional GIS applications. In this study OSM data quality is analyzed using shapefiles downloaded from CloudMade servers. However such convenience comes with sacrificing some information in the raw OSM data. Information about OSM volunteers is not included in the converted file of the study area. Raw data are exported from the OSM website to investigate patterns of OSM volunteers.

Non-spatial Information

In this study non-spatial information consists of text-based geographic information and photos. Both require unique data exploration methods. For text-based geographic information, generally there are two methodologies to narrow the scope of

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[21] http://cloudmade.com/

data and focus efforts on data that are important to decision making. One way of focusing is automatic and is termed data mining. The other way is manual, and is called data exploration. Data mining is generally applied on large datasets. The process is automated by algorithms which may incorporate aspects of artificial intelligence and machine learning. The web-based version of the technique is called web mining, which encompasses areas as web usage mining, web content mining, and web structure mining (Liu 2006). In practice web mining searches and locates pertinent datasets, and organizes those data for next stage of inspection, which is data exploration. Data exploration is a human-centered approach for analyzing a large collection of data for characteristics like structure, patterns, and pertinence. Common technologies for data exploration include statistics, structured database query, multidimensional visualization, and automatic clustering and organizing data around common features. Web mining and data exploration are two techniques used in this study to explore patterns in text-based VGI.

Photos taken by ordinary people are non-traditional geographic information that proliferates with web2.0 technologies. One of the most popular photo sharing service is Flickr. Most photos are contributed by individuals for fun. However the aggregation of these pictures provides new method for study emergency scenes. Photos on Flickr have tags defined by users, which can be used for search and group purposes. Keywords searching is one way for discovering photos. Some other photos have geographic location information embedded. Those photos can be mapped. Location information also can be inferred from locational tags assigned by users, however these kind of locations are often coarse. For photos, there exist no effective ways to automatically index them based on contents except those annotated by contributors using tags. Therefore it mostly relies on people to index them manually in the phase of data exploration.

The purpose of web mining and data exploration is to effectively discover and gather VGI. One tool for the task is Yahoo! Pipes. Yahoo! Pipes[22] is an open free web service for aggregating and processing information from multiple sources. Pipes provide predefined functional components, and by integrating different components, Pipes can be used for mapping information. In this study it is used for aggregating VGI from selected sites and clustering and organizing VGI. Figure 3 shows the general data aggregation procedure.

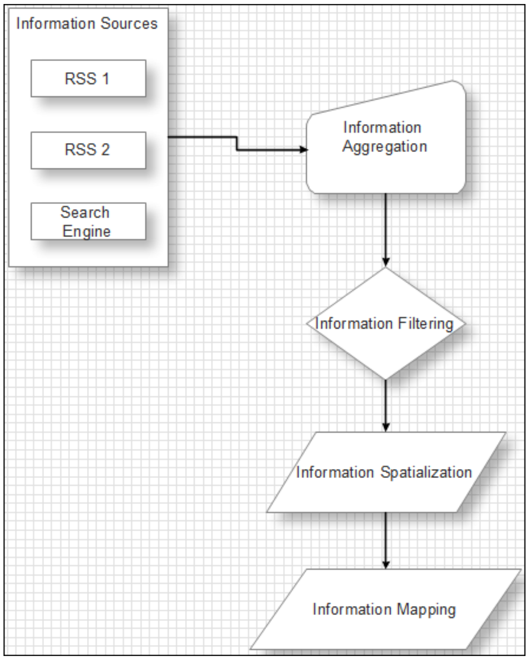

Figure 3. Data processing procedure.

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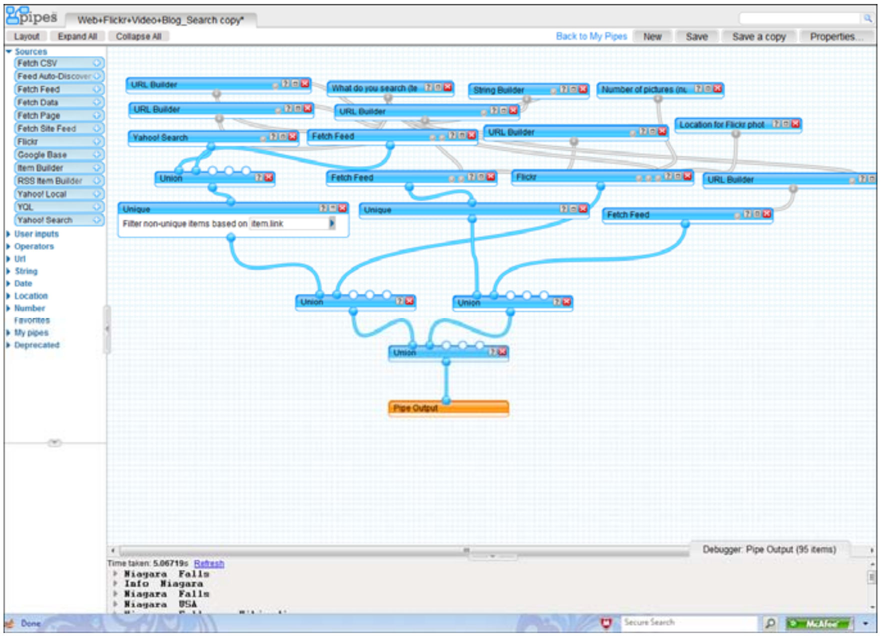
[22] http://pipes.yahoo.com/pipes/

Based on tasks different function components are integrated. As an example Figure 4 shows a Pipes developed for collecting and organizing information on San Diego Hilton Hotel explosion in 2008. Source components used include URL Builder, Location Builder, Text Input, Google Base, Yahoo! Local, and Fetch Feed. Operator components include Filter, Union, and Unique.



Filter non-unique items based on item.link

```
Time taken: 5.06719s
Niagara Falls
Info Niagara
Niagara Falls
Niagara USA
```

Figure 4. Yahoo! Pipes for VGI Aggregation.

The result is a list of web contents on the emergency including news, blogs, and photos. After geospatial and non-geospatial information are discovered, they are saved for data processing.

3.3. Data Processing

Data processing includes data collection, preprocessing, and processing. The goal is to make data ready for analysis. The study is committed to investigate VGI's potential implementations in community emergency management. In order to achieve the goal this study starts by understanding volunteers' collaboration through a wiki mechanism, then assessing the quality of VGI. Volunteers' interactivities are studied through examine historical records of Wikipedia entries, and HistoryFlow[23] is applied to visualize volunteers' interactivities. Therefore data processing is to prepare historical records of Wikipedia for visualization. OSM is a typical product of VGI, and it data quality is assessed. Indicators of data quality are calculated and mapped using ESRI ArcMap9.3.

Spatial Information

One of our study areas (Figure 5) is Houston metropolitan area that includes 5 counties surrounding the Houston urbanized area called the Greater Houston. In this article the quality of OSM's highway information is studied. OSM operates in wiki mode, whose information quality is maintained by a mechanism close to the effect of peer review. Eric S. Raymond in the essay 'The Cathedral and the Bazaar' calls it the Linus' Law that 'given enough eyeballs, all bugs are shallow'. Users can upload GPS data, out of copyright maps, or public domain data to OSM, or annotate aerial photographs from Yahoo! under the agreement between OSM and the company. OSM data are open to registered users for edits such as correcting errors, adding attribute values, or deleting features. For more information regarding OSM see (Haklay and Weber 2008). As

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[23] http://www.research.ibm.com/visual/projects/history_flow/

Wikipedia articles, which have more editors, are better than those with fewer editors (Wilkinson and Huberman 2007; Kittur and Kraut 2008), OSM is expected to improve its quality with more users.

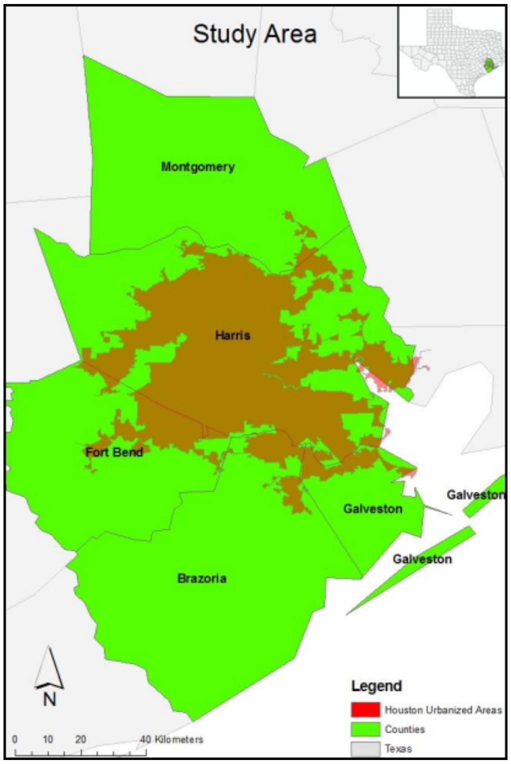

Figure 5. Study area 1 for assessing OSM data quality.

Transportation data from the Texas Strategic Mapping Program (or StratMap) are used as the authoritative data. By implementing 2004 DOQ imagery as references, the second version (Transportation Ver. 2.0) of StratMap transportation data improved spatial quality in urban areas, and 150,000 miles of new roads are added to the datasets comparing with the first version. For the DOQ data, the National Map Accuracy

Standards (NMAS) stipulates that 90 percent of check points must not exceed 33.3 feet (about 10 meters) at the scale 1:12,000. Independent studies show that the mean RMS errors for the checkpoints are between 1.7 meters and 3.2 meters depending on the measurement techniques. DOQ was used for improving the quality of TIGER (Topologically Integrated Geographic Encoding and Referencing system) dataset (O'Grady 2001).

OSM data for the study area are downloaded from the CloudMade website (www.cloudmade.com). CloudMade is a third-party service provider that directly utilizes OSM data. The reasons we use data from CloudMade, are first OpenStreetMap website puts restrictions on the download data size, and it takes lots of time and labor to download the whole area in small pieces; second CloudMade offers open APIs to access its web mapping services, by using data from its website, we have understanding of its data quality. The OSM data are last updated on July 08 2009 on CloudMade website when we download. Here we adopt the highway shapefiles converted by the CloudMade. The data have three attributes about the highways: road types, road name, and one-way information. CloudMade strips off OSM user information from its shapefile. In order to study the user information, we managed to download OSM data from its website for the Houston urban area and convert the data into shapefile with a free tool OSM2SHP[24].

Study shows that during emergency evacuation, major highways especially primary highways are the most relied on evacuation route by evacuees (Dow and Cutter 2002). In this study the quality of OSM's major highway data is focused besides the quality of the overall OSM highway data.

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[24] http://code.google.com/p/osm2shp/

OSM uses tags to define classes of roads. All road features share the key "highway", and by assigning different values (e.g., motorway, truck, or primary) to the key, roads are classified into different classes. StratMap transportation dataset uses the Feature Class Codes (FCC), which group roads into 8 classes (A00 – A09 road classifications are not used). In order to assess the OSM quality for evacuation purpose, major highway roads are divided into three classes. The classification and corresponding relationships between both dataset are shown in Table 3.

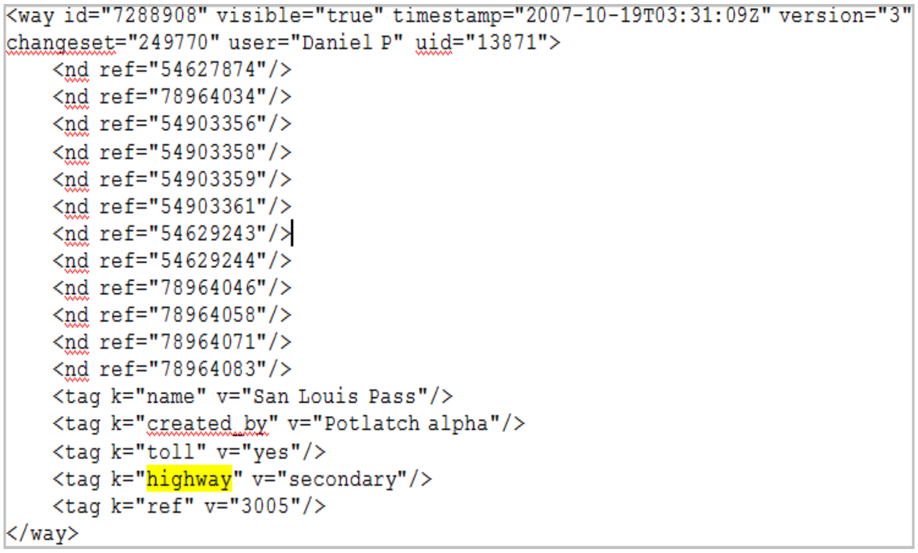
Table 3. Classification of road types.

	OSM Highways	**StratMap Roads**
Class 1	Motorway, Trunk	**A1** (Primary highway with limited access)
Class 2	Primary	**A2** (Primary road without limited access)
Class 3	Secondary	**A3** (Secondary and connecting road)

In order to assess OSM data quality in ESRI ArcMap, OSM road data are converted into shapefile format. Nodes and ways carry tags that describe characteristics of the feature, such as road, landmark, or building. OSM implements XML-based file format to store all kinds of information. Figure 6 presents an example showing XML information for a road.

This XML file segment shows a way feature that comprises 12 nodes. It is a secondary highway road, whose name is ‘San Louis Pass’. Currently, most GIS tools are not capable of processing OSM data. In order to analyze OSM data, they are converted into shapefile format in this study.

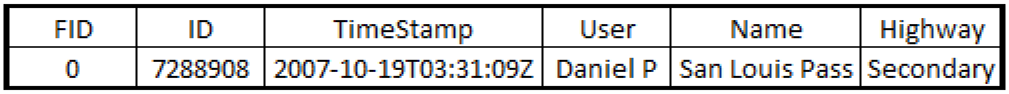
Features are converted into layers based on feature types. The general feature types are place, highway, land use, water way, railway, amenity, and tourism. All types of features are stored in the same OSM file. The first step is to extract features that share the same tag, which defines their feature type. Then, other tags are turned into attributes of the features. So, for the above road, Figure 7 shows it in shapefile format.



```
<way id="7288908" visible="true" timestamp="2007-10-19T03:31:09Z" version="3"
changeset="249770" user="Daniel P" uid="13871">
    <nd ref="54627874"/>
    <nd ref="78964034"/>
    <nd ref="54903356"/>
    <nd ref="54903358"/>
    <nd ref="54903359"/>
    <nd ref="54903361"/>
    <nd ref="54629243"/>
    <nd ref="54629244"/>
    <nd ref="78964046"/>
    <nd ref="78964058"/>
    <nd ref="78964071"/>
    <nd ref="78964083"/>
    <tag k="name" v="San Louis Pass"/>
    <tag k="created_by" v="Potlatch alpha"/>
    <tag k="toll" v="yes"/>
    <tag k="highway" v="secondary"/>
    <tag k="ref" v="3005"/>
</way>
```

Figure 6. OSM XML-based file format.

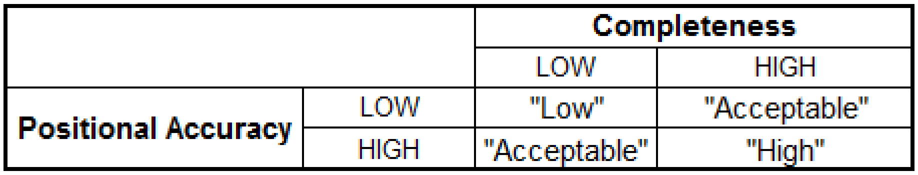
Data quality has vital influence on the quality of decisions in emergency management. Traditionally, the schema for geospatial data quality is termed the ‘five-fold way’, which includes five components, attribute accuracy, logical consistency, completeness, positional accuracy, and lineage. In this study, attribute accuracy, completeness, and positional accuracy are focused. The method applied is by comparing the three measurements between tested and reference sources. Tested source is data that are to be assessed, and reference source is selected data with known data quality or from trusted sources.



FID	ID	TimeStamp	User	Name	Highway
0	7288908	2007-10-19T03:31:09Z	Daniel P	San Louis Pass	Secondary

Figure 7. Shapefile attribute table of the converted OSM street feature.

Table 4. Decision criteria for OSM data quality.



		Completeness	
		LOW	HIGH
Positional Accuracy	LOW	"Low"	"Acceptable"
	HIGH	"Acceptable"	"High"

Attribute accuracy cares about how accurately feature characters are captured. Completeness and positional accuracy assess the topological and geometrical accuracy of features. In OSM many public data are integrated into existing data. This, on the one hand, help improve OSM coverage with less manpower, on the other hand, creates problems like duplicate points. Then, it helps to organize and manage volunteers if existing OSM data quality is known. Finally, it is important to know data quality if OSM data are used for decision making. For these purposes, a data quality model is enunciated as a pair: **DQ (Completeness, Positional Accuracy)**, with the decision criteria depicted in Table 4.

Based on the model, a set of indicators are developed. The advantage is it provides a unified measurement for OSM data quality. The method is to combine measurements of completeness and positional accuracy. The function is:

$$F(x, y) = A^{x} \times [Completeness] + B^{y} \times [Positional\ Accuracy]$$

A, B: constants, in this study they are set as 10.

$x, y \sim [0, 1]$

In the original measurement, completeness is the total road length difference between tested and reference sources. In order to unify the two measurements, the length difference is normalized.

```
IF L(OSM) > L(Reference)
        THEN [Completeness] = [L(OSM) – L(Reference)] / L(OSM)
IF L(OSM) < L(Reference)
        THEN [Completeness] = [L(OSM) – L(Reference)] / L(Reference)
```

Therefore when [Completeness] is closer to zero, it means there is smaller length difference between the tested and reference data. Combined with the positional accuracy measurement, which indicates higher accuracy when closer to 1, F(x ,y) indicates higher data quality when the value is closer to 1.

Non-spatial Information

Wikipedia is studied as an example of wiki system. As of early October 2009, Wikipedia had 75,000 active contributors and approximately 13 millions of articles in more than 260 kinds of languages with about 65 million visitors worldwide visiting Wikipedia monthly[25]. Yochai Benkler views Wikipedia as an example of commons-based peer production system, a new modality of collaboration, which is '*radically decentralized, collaborative, and non propriety; based on sharing resources and outputs among widely distributed, loosely connected individuals who cooperate with each other without relying on either market signals or managerial commands*' (Benkler 2006). Wikipedia records every edits on its contents. Information saved include editors (by registered name or IP address), edit time, and edit contents. Such information can be used for study interactivities between volunteers. Figure 8 shows differences between two versions of the Hurricane Ike entry. The left version (older version) was created by a user from the IP address 72.224.251.138 at 20:46, 15 September 2008. The right version (newer version) was created by Cyclonebiskit at 20:47, 15 September 2008. Cyclonebiskit added new information (highlighted in red) to the contents contributed by the previous user. The difference between different versions of the same entry can be visualized by HistoryFlow, which is described in next sub-section.

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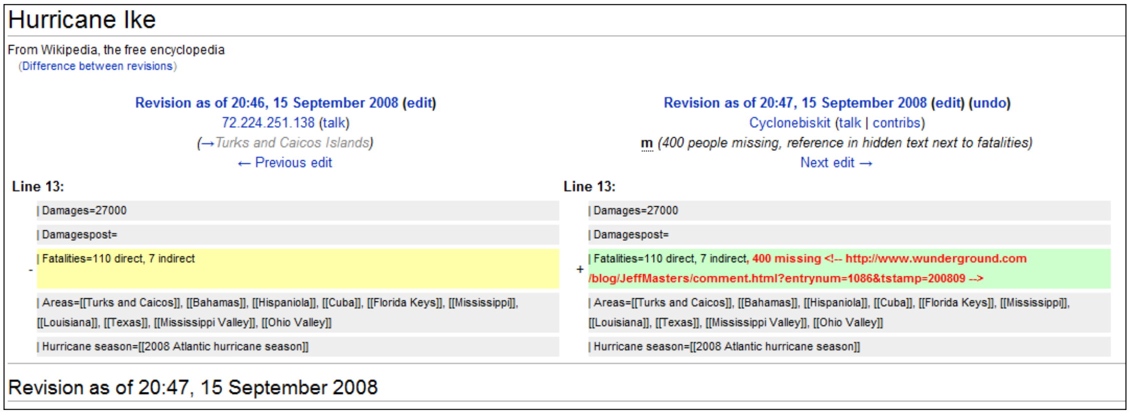
[25] According to http://en.wikipedia.org/wiki/Wikipedia:About



Hurricane Ike

From Wikipedia, the free encyclopedia
(Difference between revisions)

Revision as of 20:46, 15 September 2008 (edit)
72.224.251.138 (talk)
(→Turks and Caicos Islands)
← Previous edit

Line 13:

| Damages=27000

| Damagespost=

\- | Fatalities=110 direct, 7 indirect

| Areas=[[Turks and Caicos]], [[Bahamas]], [[Hispaniola]], [[Cuba]], [[Florida Keys]], [[Mississippi]], [[Louisiana]], [[Texas]], [[Mississippi Valley]], [[Ohio Valley]]

| Hurricane season=[[2008 Atlantic hurricane season]]

Revision as of 20:47, 15 September 2008 (edit) (undo)
Cyclonebiskit (talk | contribs)
m (400 people missing, reference in hidden text next to fatalities)
Next edit →

Line 13:

| Damages=27000

| Damagespost=

\+ | Fatalities=110 direct, 7 indirect, 400 missing <!-- http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=1086&tstamp=200809 -->

| Areas=[[Turks and Caicos]], [[Bahamas]], [[Hispaniola]], [[Cuba]], [[Florida Keys]], [[Mississippi]], [[Louisiana]], [[Texas]], [[Mississippi Valley]], [[Ohio Valley]]

| Hurricane season=[[2008 Atlantic hurricane season]]

Revision as of 20:47, 15 September 2008

Figure 8. Differences between two versions of Hurricane Ike entry.

Wikipedia always displays the newest version of a entry. Once a change is made to the current version, the updated version is displayed, and the old version is stored in the database. This mechanism makes it easy to reverse any change and restore a entry. By analyzing all old versions of a entry it reveals interactivities between contributors. Geocoding is widely used by web2.0 applications to mapping text-based information. Therefore the accuracy of geocoding has significant influence on the quality of the result map. In this study the geocoding quality of Google and Yahoo geocoding services is assessed. The authoritative data are downloaded from the GIS Map Library of the Harris County Public Infrastructure Department[26]. The data are about the locations of 111 hospitals of Harris County, which are saved in a point shapefile. Information in the shapefile consists of coordinates of hospitals, and addresses of them. Addresses are exported and geocoded by Google and Yahoo geocoding services to get coordinate information. The new coordinates are compared to the authoritative data to assess the geocoding quality.

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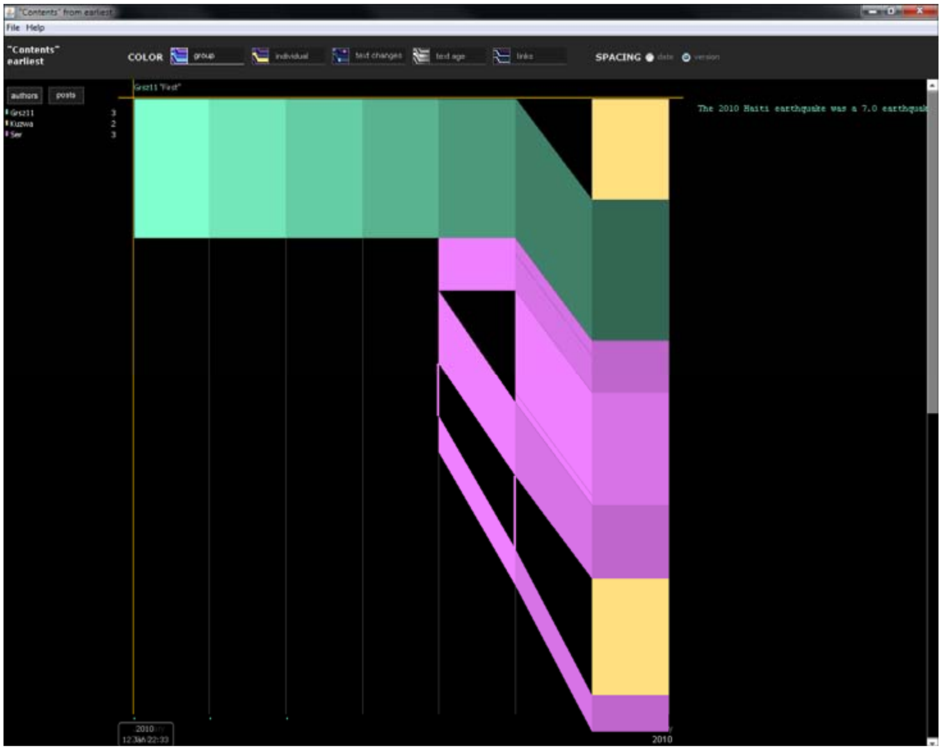
[26] http://www.eng.hctx.net/GIS/gis.htm

3.4. Data Visualization

HistoryFlow visualizes the collaborative efforts of multiple authors on producing a Wikipedia entry. The procedure is dynamic, which involves multiple authors creating, reviewing, and editing the contents. The information of whom makes what contribution at what time is recorded in the Wikipedia archive. Therefore about every Wikipedia article there is a record of editors with their activities. HistoryFlow catches those events and visualizes the relations between different events. See this webpage[27] for introduction on how HistoryFlow works.



The 2010 Haiti earthquake was a 7.0 earthquak

Figure 9. A historyflow example.

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[27] http://www.research.ibm.com/visual/projects/history_flow/explanation.htm

Next, use the 2010 Haiti earthquake Wikipedia entry as an example[28]. Three authors with their edits are displayed in Figure 9. The first author is Grsz11 who created the first version at 22:33, 12 January 2010. At the left side of the interface are list of all registered users. Users without registration their contributions are displayed in white or gray color. In the middle of the interface is the display window. At the right side is the window that display texts of the article, and the text color indicates the author.

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[28] http://en.wikipedia.org/wiki/2010_Haiti_earthquake

CHAPTER IV

RESULTS AND FINDINGS

4.1. The Development of VGI in Emergency Management

The year 2005 marked the first year that grassroots-driven emergency management is changed by VGI. In that year, Google released, by now the most well-known web2.0 service, Google Maps, a mirror world tool that enables the general public to observe and annotate the earth surface by high-resolution satellite imageries. In June 2005, Google published Google Maps API for users to integrate personal data with Google Maps service, this method is called mashup. Mashup is a totally new way for the general public to interact with web mapping service. It ignites citizens' passion for mapping almost anything that interests them (e.g., see all user-generated mashups on Google maps Mania[29]). It is a new tool for sharing geographic knowledge among the general public, which naturally includes knowledge and information related to disasters and emergencies. All these user generated contents are supported by the availability of high-resolution satellite imageries. At the same time, Google Maps helps bring high-resolution satellite imageries to the public in a nearly real-time fashion where updated information is required by the situation like after disasters. It is the first time that real-time imageries are publicly available for grassroots-driven activities such as guiding humanitarian relief operations carried out by individuals, grassroots groups, and small NGOs, who are not supported by the traditional GIS tools. In 2004 Indian Ocean Tsunami, satellite imageries are not available for the public till three weeks after the

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[29] http://googlemapsmania.blogspot.com/

tsunami. In 2005, after Hurricane Katrina hit New Orleans, Google Maps quickly released satellite imageries on September 7th, which help users to view the extent of the flooding in the city. In 2010 Haiti earthquake, the first satellite imagery is released to the public in 26 hours after the earthquake. The year 2005 is important not only because Google Maps starts a new era of geography in that year, but also because many other web2.0 services that enable VGI are published around that year, which are gradually adapted for humanitarian purposes. Examples are Flickr, YouTube, and OpenStreetMap. In this sub-section the implementations of VGI in several major disasters and emergencies since 2004 are investigated. These include 2004 Indian Ocean Tsunami, 2005 Hurricane Katrina, 2008 Sichuan Earthquake, 2008 Hurricane Ike, and 2010 Haiti earthquake. The including of 2004 Indian Ocean Tsunami is to help illustrate the changes made by Google Maps and other web2.0 tools. The analysis focuses on the contents of VGI and the communication mechanism of VGI. The results help provide answers to the questions: what VGI is created during emergency situations, and how VGI is distributed through various web2.0 services, such as blogs, photos, videos, or map mashups? At the same time it looks at data requirements of organizations in their response to a disaster.

2004 Indian Ocean Tsunami

The 2004 Indian Ocean Tsunami was caused by an undersea earthquake that occurred on December 26. The lack of early warning systems and means to disseminate emergency information to the general populace around the area make the tsunami one of the deadliest disasters in human history. The international organizations responding to the disaster include the grassroots organizations that normally lack established framework for cooperation, and are good at improvising existing tools that will fit the purposes. The improvised tools are blogs and emails. Blogs act as information hub for people looking for help and families. Email is the communication tool that connects different people.

This study looks at two blogs that are established right after the tsunami. The first blog post emails from users. The first post makes an announcement that people can send messages to a designated email address, and mailed-in messages are posted on the blog. The second blog is a gateway that aggregate blogs from other websites on the tsunami. Posts from 29th to 31st are analyzed on their contents, and results show that:

- The purposes of messages can be loosely grouped as volunteers seeking and sharing opportunities to help disaster affected people, disaster affected people looking for family information and relief resources, and personal observations of situations.
- Geographic information in the form of text commonly exists in many messages.

However, the way these messages are distributed in emails and blogs is not ideal. First, email has a peer-to-peer character, which makes it difficult to be massively distributed, and greatly decreases the chance that an ad hoc connection is established, which means a request is answered by an anonymous responder. Then text-based geographic information is not intuitive. It needs a map to provide base information. And to find usable geographic data is a hard challenge in many emergency management operations. The problems exposed by the Indian tsunami include: outdated and low quality satellite imageries, restricted access to geographic data, and difficult to assess the usability of geographic data. In response to the Indian tsunami, VGI, almost entirely created in the form of blog, cannot effectively assist in problem solving.

2005 Hurricane Katrina

The utilization of VGI for assisting emergency management can be traced back as early as in the Hurricane Katrina disaster in 2005. Firstly, VGI is a new method of distributing emergency information through the Internet. Websites take a new role as hubs of crisis information. Blogs, wikis, and Google Maps mashups were created by volunteers to assist displaced citizens find shelters or families (Palen and Liu 2007). Blogs, such as Katrina Aftermath[30], are established to share personal stories, images, family information among survivors. At the same time, many of these websites work as non-official information hubs for publishing information related to relief resources. Personal appeals by the victims are made to the general public through these blogs. Besides blogs, mirror-worlds tools, such as Google Maps/Earth, are widely used for emergency information seeking and publishing purposes. The stories are covered by articles from three major news agencies (Ewalt 2005; Hafner 2005; Thompson 2005). People of New Orleans used Google Maps/Earth to collect and distribute information about the disaster (Miller 2006). Some of these examples can be found at this blog[31]. The improvisation of blogs and web-based mapping tools for emergency information distribution can be found almost in every major disaster after 2005.

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[30] http://katrina05.blogspot.com/

[31] http://googlemapsmania.blogspot.com/2005/09/summary-of-all-known-google-maps.html

At this moment, many data from VGI are point-based attribute data which provide information about a location that is presented on Google Maps. There is information about shelters[32], landmarks[33], and houses available for the displaced[34]. The importance of Google Maps can hardly be overestimated in the creation of volunteered geographic data. While traditional geospatial technology has difficulties to integrate and distribute geographic data in disasters, Google Maps almost immediately invents a new and convenient means for both professional and laypeople to find and visualize geographic data (Schutzbery and Francica 2005). However, how VGI might assist official emergency management is not clear. The failure of official emergency management in Hurricane Katrina is partly because of the lack of accurate and updated geographic information. Meanwhile there are Google Mashups created by volunteers showing flooded places[35]. There are 12,885 photos, uploaded by citizens, about Hurricane Katrina on Flickr. How to harvest this non-traditional geographic information is a challenge.

2008 Sichuan Earthquake

Volunteers using web 2.0 technologies to collect, synthesize, and disseminate disaster information is not confined to the United States of America alone. It is a global trend. In China, the Internet has stepped up to assist organizing grassroots operations. Two examples exemplify this trend. Internet started to play a significant role for emergency response and relief in 2008 Chinese winter storms, which were a series of disastrous ice storm events impacting southern and central China from January 25 to

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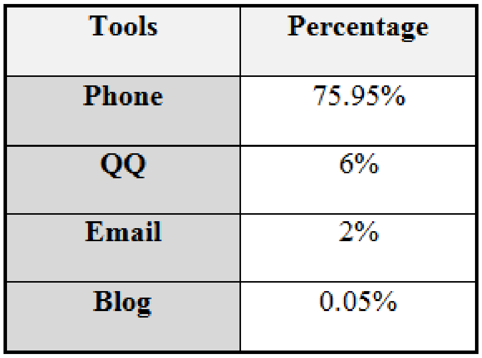
[32] http://www.katrinashelter.com/maps/
[33] http://krioni.100free.com/interdictor.html
[34] http://www.refugemap.org/
[35] http://www.gearthhacks.com/dlcat72/Hurricane-Katrina-and-Flooding.htm

February 6 2008. The climax of self-organized volunteers through Internet for emergency response and relief happened in the 2008 Sichuan Earthquake. The earthquake occurred on May 12, 2008 at 14:28:01.42 CST in Sichuan province. It was measured at the surface wave magnitude 8, and estimated 69,000 casualties. Approximately 4.8 million people were left homeless, and 15 million people live in the impacted area.

At 14:35:33 CST the first message about the earthquake was posted on Twitter by a user at Beijing, and the content was about the slight vibration of the building caused by the earthquake. The first report on Bloomber.com was 22 seconds after the first Twitter post. Then at 14:39 CST, another traditional news website Reuters.com made more detailed report about the geographic location and the magnitude of the earthquake. Most messages on Twitter still focused on the impact at the Beijing region without further update at that time. Traditional journalisms with their capacity and resources have superiority on holistic reports on valuable news, while the emerging grassroots journalism has the advantage of capturing happenings in people’s daily life. Internet connected the disaster affected people with families, friends, and the outside world. Photos, videos, and blogs describe the earthquake from individual perspective were published online. Through these postings outside world gained knowledge about the earthquake. A survey of China’s social network shows that lots of messages are created by college students through various web2.0 applications (Xiao and Zhu 2008). These messages tell personal stories, request volunteers, and offer help resources. The volunteered information is valuable for the relief operation. Shortly after the earthquake, government agencies could not find proper positions for landing helicopters to rescue people from an isolated village using any existing maps. One online message from a contributor who once lived at the region described a location suitable for a helicopter landing. The message after more than 2,000 redistributions by volunteers finally caught the attention of the military. It led to the rescue of thousands of lives (West China Metropolis Daily news 2008).

Although Google enters China in 2006, Google Maps and its mashups are not widely used by volunteers in the aftermath of the earthquake. Volunteers share information through forums, such as Tianya[36]. Although geographic information such as location of volunteers, location of victims, or location of relief resources is commonly provided in posts on Tianya, the information is not displayed in maps. Concurrently, email and other web2.0 applications are not widely used as communication tools for coordinating relief operations. Most of the relief coordination activities are via mobile phones or land-line phones. A post on Tianya is used by volunteers to share relief resource information (totally 1,904 entries). Table 5 shows how different communication tools are used by volunteers.

Table 5. Web 2.0 tools used by volunteers for emergency communication.



Tools	Percentage
Phone	75.95%
QQ	6%
Email	2%
Blog	0.05%

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[36] http://www.tianya.cn/

Results on VGI in Sichuan earthquake indicate that the major form of VGI is text-based. Although these messages are potentially valuable for government and official emergency management agencies to assess local situations, they are not aggregated and mapped. Google Maps and other web-based map applications are not widely used by volunteers. Maps are used for finding places for most of the time, and are rarely implemented for displaying crucial emergency information.

2008 Hurricane Ike

Hurricane Ike formed on September 1, 2008 and dissipated on September 14, 2008. It was the most costly hurricane for the U.S. in 2008, and would likely to be the third costliest hurricane on record with the cost of its rampage along the Gulf Coast reaching U.S. $22 billion, just behind Hurricane Katrina in 2005 and Hurricane Andrew in 1992. The center of Hurricane Ike made landfall at Galveston, Texas around 2 a.m. CDT on September 13, 2008 as a Category 2 hurricane. But the enormous size of the hurricane, nearly as large as the size of Texas, caused huge storm surge of 10 to 15 feet above normal tides, which was rare for a hurricane at Category 2, and caused the worst damage of Hurricane Ike. Since the initial stage of the formation of Hurricane Ike the web communities have given attention to the unfolding story. Next several examples are presented to help demonstrate the magnitude of VGI efforts on covering Hurricane Ike.

First, the blog communities are surveyed. Using keywords “Hurricane Ike 2008” search in Google Blog Search returns 150,518 blog entries which are created between September 1 and November 14. As the search dates are defined as between September 1 and September 19, which are the dates Hurricane Ike became a tropical disturbance and three days after the hurricane finally dissipated, there are 82,714 blog entries. It is a daunting work to go over all search results, instead only the first one hundred most relevant results are examined for their contents. The bloggers have various identities, for example: citizen bloggers, experts (e.g. chief meteorologist of ABC13: Tim Heller), politicians (e.g. Speaker of the House: Nancy Pelosi), and organizations (e.g. Google Earth and Maps team and ArcGIS-Explorer team). The contents of blogs cover a wide spectrum of information types including: location information (e.g. projected hurricane paths or current position of the hurricane), meteorological information (e.g. current wide speed, hurricane movement speed, and pressure), damage information (e.g. the hurricane effects on oil and gas markets, photos of damaged houses and flooded areas, or personal losses), and personal life logs which recorded detailed personal activities and experiences during the striking of Hurricane Ike.

Further exploration of blog contents reveals that blogs can be categorized according to their data resources and creators' capacities on information integration and analyzing capacities. NOAA is the most important source for geographic information, meteorological information, satellite imagery, and aerial photos. Many bloggers updated their reports on the hurricane based on information retrieved from NOAA. TV news are the second important source for most bloggers, who integrate video clips of weather broadcasts or news on YouTube in their blogs. Flickr is probably the most important source for photos, not only because a large proportion of citizens share their photos using its service, but many NOAA imageries and aerial photos taken by governmental organizations are also uploaded to Flickr. Then there are obvious differences in the blog subjects between organization, expert, and citizen bloggers. Organization bloggers with their multiple information conduits can provide the most valuable blogs. One example of such blogs was created by Alexis Madrigal (2008) at Wired.com on September 12, and demonstrated the worst situation of storm surge risk for the Gulf Coastal area based on information provided to Wired.com by the First American Proxix Solutions, which is an insurance risk management firm. Then there are expert bloggers, who might not have multiple conduits for internal information, but can integrate public available information and make professional analysis and predictions. The blog created by Tim Heller (2008) on September 19 offers an example, and provides a through recounting of the whole procedure of Hurricane Ike. The third group is citizen bloggers, whose blogs are of various levels of quality and cover wide varieties of subjects. Some just recount general news about the hurricane, some put maps, photos, and videos together in one blog, some record personal life details during the hurricane, and etc.

Second, map mashups are searched. The maps for basic geographic information include Google Maps/Earth, Microsoft Virtual Earth, Yahoo Maps, NASA World Wind, and OpenStreetMap. Mashed-up resources include photos (e.g. loc.alize.us or geocoded Flickr photos), videos (e.g. YouTube on Google Maps), or other web services (e.g. Stormpulse). The mashup activities may be simple like integrating a photo on Flickr with Google Earth to show the damage of Hurricane Ike using a KMZ file, or sophisticated like creating an animation map showing information about the hurricane using Adobe Flash technology. Geocommons provides convenient services for citizens to create their own map mashups easily. In response to the hurricane, Most volunteers’ efforts are contributed to searching and uploading data resources, which are aggregated from scattered online sources. One example is the Power Outage maps of several U.S. states on

September 15. At that time there were no governmental reports about the exact detail (the number of power outages by zip code) of power outage. One volunteer contributed great effort for searching online for the information, and finally found the data on energy companies' websites. It is hard to estimate the actual impact of these volunteered maps at this moment, but with the volunteer's contribution to explore the data and share them on a more popular website than some energy companies' websites, it makes the data more available to the public and for potential usages.

Third, the Twitter community in Hurricane Ike is studied. Twitter is a micro-blogging service, which was launched in October 2006. Twitter can be used across multiple platforms. It creates an effective mechanism for distributing information across the networked users. These advantages have made Twitter an efficient communication tool that is quickly adopted by over 3 millions of users. The integration of harsh-tag function has made information distributed by twitter more traceable. Because of Twitter's popularity and functionality, its usage for distributing emergency information would be natural. A study shows there are two spikes in twittes during Hurricane Ike (Hughes and Palen 2009). The first spike appears when the hurricane made landfall in Cuba on September 8th, and the second when it hit the US coast on September 13th. This pattern of information spikes is reflected in the Wikipedia activities as well. Figure 10 shows the daily edits on the Hurricane Ike Wikipedia entry.

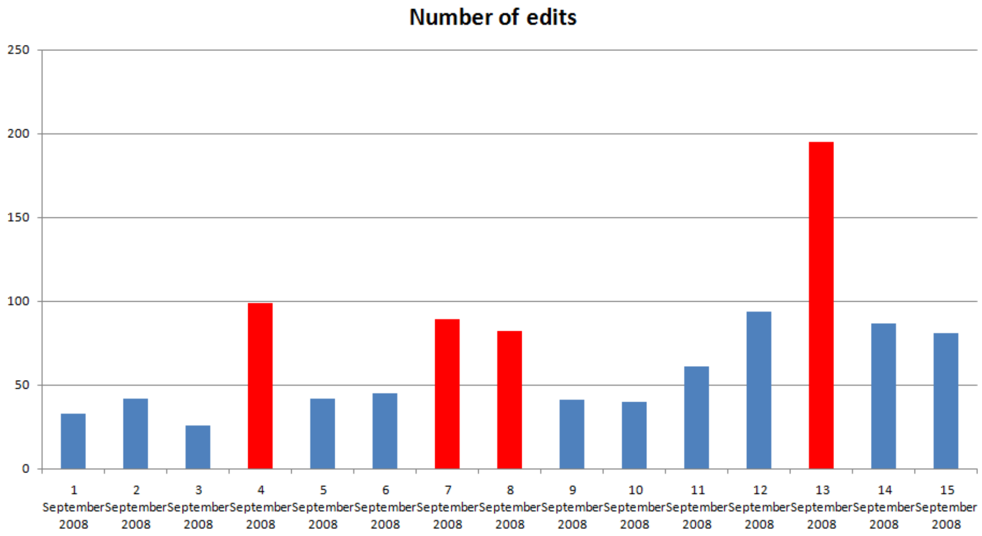

Figure 10. Daily edits of Hurricane Ike Wikipedia entry.

The first spike of edits happens when the hurricane became the most intense storm thus far in the 2008 Atlantic hurricane season. The second spike and the third spikes appear when the hurricane made two landfalls.

Government agencies, institutions, private organizations, NGOs, and citizens are on Twitter. During the hurricane, Twitter is used by NOAA to distribute updated information, local news channels to broadcast local situations, and RedCross to send disaster relief information. While organizations make regular posting on Twitter, Hughes and Palen, by studying 59,963 twittes about Hurricane Ike, show that the majority of users (over 70%) only make 1 post, and less than 10% users make multiple posts about the hurricane.

Up till now, citizen contributed geographic information about disasters is commonly witnessed, and VGI is distributed in many web2.0 applications and in many forms. There haven’t been any framework or tool to harness these types of VGI. Although VGI is potentially valuable for a data commons to meet the information requirements of disaster affected people, the link between information provider and information seeker is still broken by now. The establishments of two non-official organizations change the situation and suggest new way for applying VGI for emergency management. The first one is Crisis Commons (CC) which is founded in March 2009, and the second is the Humanitarian OSM Team (HOT). The VGI activities are organized and coordinated by these two groups which make the outcomes more suitable for emergency management tasks. In the aftermath of 2010 Haiti earthquake, VGI illustrates its value to assist emergency response operations.

2010 Haiti Earthquake

Haiti earthquake occurred at 16:53 local time on January 12, 2010. The epicenter located 16 miles west of Haiti’s capital, Port-au-Prince (PaP). The magnitude of the earthquake is 7.0 Mw. From the very beginning of the emergency response phase for Haiti, the OSM community participated the humanitarian relief actions and generated maps that were urgently required by field work teams. A wiki site for the OSM project[37] in Haiti has been established by the Humanitarian OSM Team to record key events, to register resources, and to coordinate activities of different groups and individuals. At the same time another wiki site has been setup by the Crisis Commons project[38] for sharing information among NGOs, citizen volunteers, humanitarian relief agencies, and many other organizations that are involved in Haiti relief actions. In this study records on both

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[37] http://wiki.openstreetmap.org/wiki/WikiProject_Haiti

[38] http://wiki.crisiscommons.org/wiki/Main_Page

wiki sites are studied for the purpose of tracing information flow among different organizations across different geographic regions. The information being focused is VGI. A synoptic view of VGI applications in Haiti is given to help make a background of this study.

- Before the earthquake, United Nations and Doctors without Borders are carrying out humanitarian operations in Haiti. MINUSTAH is UN’s stabilization mission in Haiti. MINUSTAH has produced maps and geospatial data of Haiti, after the earthquake, permission is granted by the MINUSTAH to OSM to use its data for mapping. Shapefiles based on MINUSTAH data are available on Geocommons.

- Google makes aerial imagery taken by GeoEye public for humanitarian activities in Haiti. Google Map mashup is quickly made available to the public to perceive damages made by the earthquake. At the same time OSM volunteers are using the imagery to map spontaneous camps of earthquake victims.

- Many aerial imageries are available to the public who wish to help in relief actions. Imageries come from several countries’ institutions, international organizations, and companies. OSM community uses these imageries to extract data of collapse buildings, spontaneous camps, and road systems. At the end of January more than 600 volunteers contribute to OSM Haiti; 24,000 features have been mapped; and more than 40,000 road features are mapped.

Such data are turned into maps that can be uploaded to Garmin GPS for field works.

- Volunteers are organized in the form of Crisis Camps, where citizens can meet and collaborate on crisis relief projects. From January 16th to March 7th, 28 crisis camps are organized in 17 cities of 5 countries. Volunteers work on projects like collecting RSS feeds, GIS data translation, tool developments and produce OSM data.

- Project 4636 and Ushahidi are setup several days after the earthquake. Haitians send emergency SMS to the number 4636, and the information is relayed to corresponding organizations to provide aids to senders. Many messages are in Haitian official language: French and Creole. Those messages must be translated before being processed. The work of translation and categorization is given to volunteers organized by two web2.0 startups: CrowdFlower and Samasource. Project 4636 provides a system that is very similar to the 911 system in US, to which people can send emergency message requesting help. Ushahidi is an open source mapping system for visualizing emergency information. Part of the SMS sent to project 4636 is georeferenced and mapped using open web mapping services.

The geographic convergence of people, material and information happens in virtual space as online social convergence (Palen 2008). While this is a trend that has been observed in previous disasters, the constant integration of mobile technology and web2.0 services has changed VGI applications in Haiti earthquake. The online virtual space and the physical space are increasingly converged as a whole new cybernetic space. Information which is created in virtual space has indispensable value to decision-making in physical space. Next, three types of VGI are discussed: OSM maps about Haiti, local reports collected by Ushahidi, and twittes about Haiti earthquake.

OSM

Right after the earthquake, when the emergency relief organizations rush to the rescue of Haitians, lack of local road information is a major obstacle. OpenStreetMap community responds, and with help from volunteers, in several days, a detailed map of Haiti road networks is drawn, which can be uploaded to GPS for carrying out field work. Figure 11 shows OSM data in the capital area of Haiti before the earthquake.

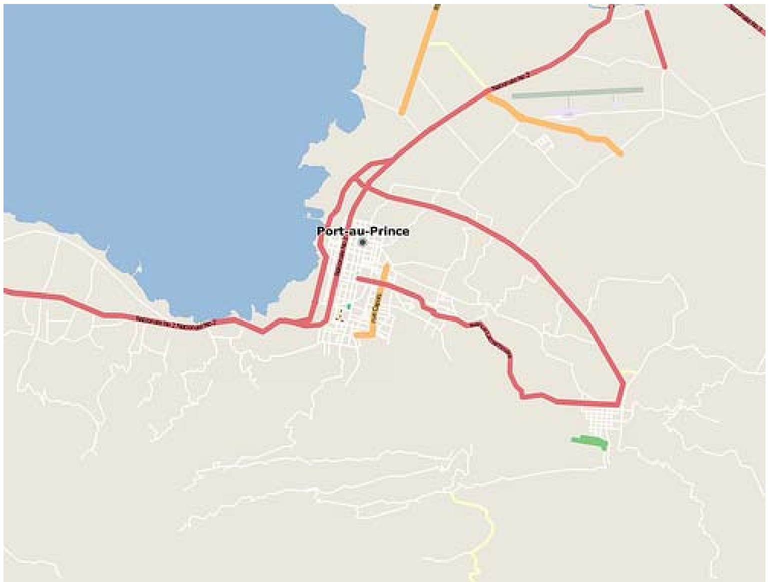

Figure 11. OSM for PaP before the earthquake[39].

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[39] Cited from http://brainoff.com/weblog/2010/01/14/1518

Before the earthquake, except for major roads, other roads especially in residential areas are not mapped. A detailed road map of residential areas is crucial for carrying out relief operations. This urgency is immediately realized by the OSM community. Camps of volunteers are organized where volunteers with various skills can provide help (Pool 2010). Road networks are created by tracing remote sensing imageries. The result is displayed in Figure 12.

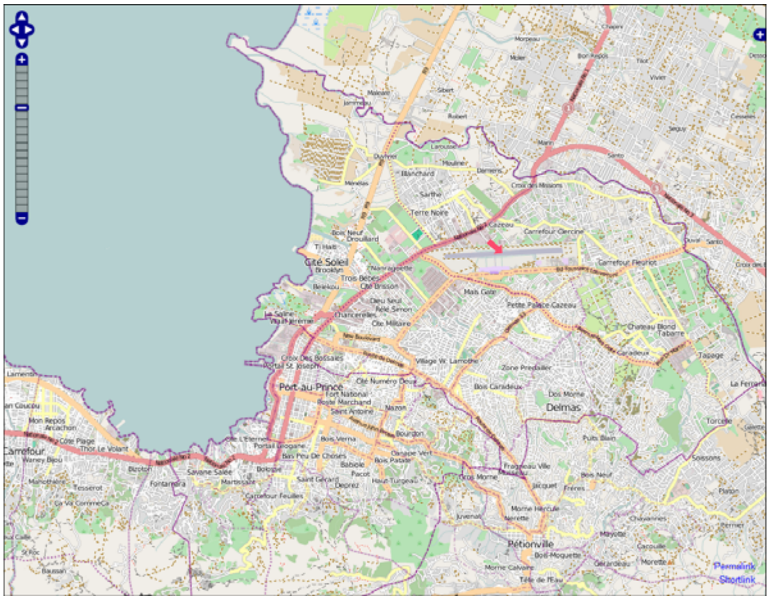

Figure 12. OSM for Haiti PaP as of 02/05/2010.

According to data extracted from OSM[40], totally there are 38 OSM volunteers before the earthquake. Two days after the earthquake, the number jumped to 71 on January 14, 2010. At the end of January the number is above 600 (Figure 13).

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[40] http://cortesi.com/2010/01/openstreetmap-haiti-statistics/

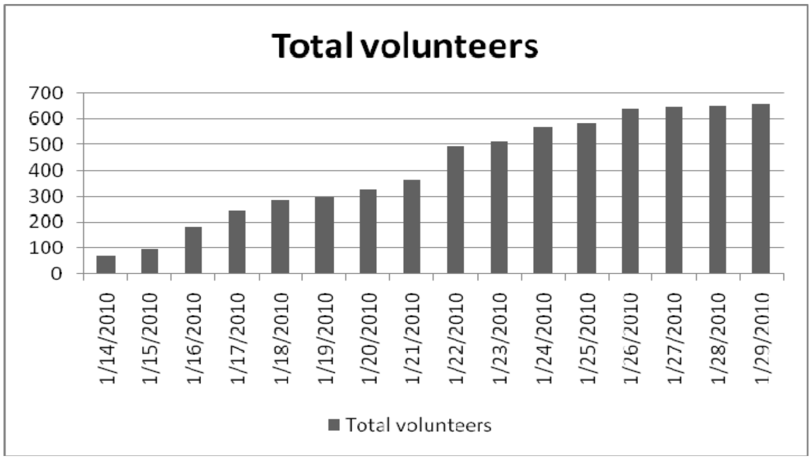

Figure 13. Total volunteers for Haiti OSM as of 01/29/2010.

The collaboration of volunteers has helped create a detailed road map about Haiti with:

- More than 40,000 road features being mapped;
- In the residential areas, 10,000 tracks, 2,000 roads, 3,000 paths, and 9,000 unclassified road features being mapped.

Meanwhile, the openness of OSM framework makes it easy to integrate many other types of emergency information. Geographic information uploaded to OSM consists of:

- Building information, which was collected by field workers or extracted from high-resolution imageries by volunteers. Around 16,000 buildings are mapped among which 7,000 buildings are collapsed;

- Location of refugee camps, which were discriminated by volunteers using high-resolution imageries. Around 2,300 refugee camps were counted. Via this grassroots way locations of refugee camps are available for field workers before official information was available.

During the climax of response operations, updated OSM data are available for every 15 minute. Data from different resources are constantly integrated. OSM data are widely used by official humanitarian organizations, disaster relief agencies, NGOs, and many grassroots organizations. In World Bank's situation room for the Haiti earthquake a printout of OSM is used for infrastructure information and organizing rebuilding activities. GPS that equipped with OSM data is used by RedCross fieldworkers, who are impressed by the accuracy of the data. OSM is widely used by institutions and offices of United Nations, such as Office for the Coordination of Humanitarian Affairs (OCHA), UN Institute for Training and Research (UNITAR), Food and Agriculture Organization (FAO). In order to collaborate with Haitian government on rebuilding projects, OSM send hard drives with OSM data and tools to the Haiti government, therefore build a connection between the grassroots-driven OSM community and the local government.

OSM data have information about locations of:

- Administrative boundaries
- Hospital
- Police station
- Radio and TV station

- Road features

Most OSM data are created by using information extracted from high-resolution imageries, or by integrating data from other resources. UN institutions and offices share collapse building information with OSM. OSM data generated from GPS tracks are rare. Only 23 GPS tracks are collected in Haiti by 2 volunteers.

Ushahidi and Project 4636

There is probably no better way to illustrate the potential of GeoWeb2.0 and VGI for emergency management than the project 4636[41]. It presents a new model of emergency information management via social networking tools, GeoWeb2.0, and an army of volunteers. It starts with a tweet sent by a Twitter user, who is a non-profit organization officer in Africa, about establishing a SMS service for Haitians right after the earthquake (Cutter 2010). Within three days, a system is built using service provided by Digicel, the largest wireless carrier in Caribbean. Organizations onboard include U.S. government, non-profit organizations, startup companies. Haitians send emergency SMS to the number 4636, the information is processed and is sent to corresponding organizations for providing aids to senders. Many messages are in Haitian official language: French and Creole. Those messages must be translated before future process. The work of translation and categorization is given to volunteers organized by two web2.0 startups: CrowdFlower and Samasource. Figure 14 shows physical locations of translators of the project as recorded by their computers' IP addresses.

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[41] http://blog.ushahidi.com/index.php/2010/02/08/project-4636-an-info-graphic/

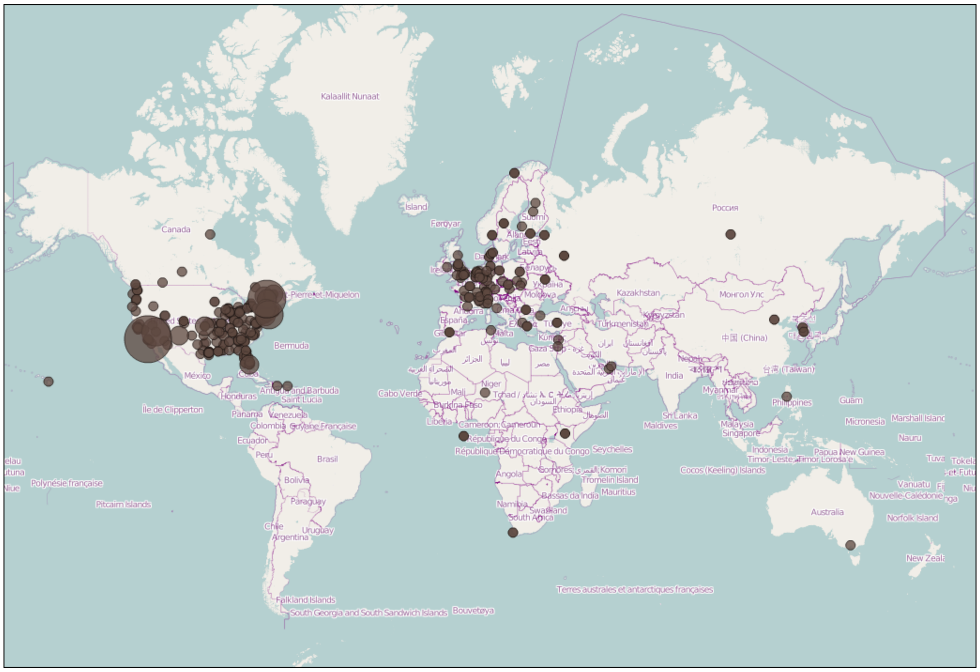

Figure 14. Physical location of project 4636 volunteers.

Project 4636 provides a system that is very similar to the 911 system in U.S., to which people can send message to ask for help. The difference is the 4636 project is driven by volunteers and supported by open source platforms and tools.

Ushahidi is an open source mapping system for visualizing emergency information. The general public can send SMS to a local mobile phone number; the georeferenced messages are mashed-up with web mapping services. Ushahidi is one of the core functions for the project 4636. After Ushahidi Haiti was setup, the number is broadcasted via local radio stations. After a message is received, a volunteer processes the message. The process includes translation categorization, and georeferencing. Messages that are determined to be useless are discarded. Useful messages are saved and pins are put on map to mark the geographic locations of messages. All messages are open to the public, and the humanitarian communities can respond to the requirements of local community. SMS mapped on Ushahidi is only a part of the messages sent to 4636. Many messages sent to the number are not actionable therefore are not forward to anywhere. Some messages are sent to other organizations like US Coast Guard or RedCross. By February 4th, totally 12,567 messages are sent to 4636. Figure 15 shows the distribution of the number of messages received daily.

Among the raw messages, 2,316 messages (18.4%) are georeferenced and have coordinates. Their locations can be mapped on Ushahidi. Figure 16 shows the daily number of messages mapped by Ushahidi.

Ushahidi Haiti is widely reported by news and blogs. Official agencies and humanitarian organizations recognize the efforts made by the grassroots communities. It creates a means that local people request helps from emergency relief agencies. The following map (Figure 17) presents the geographic distributions of food shortage information that is sent by local Haitians.

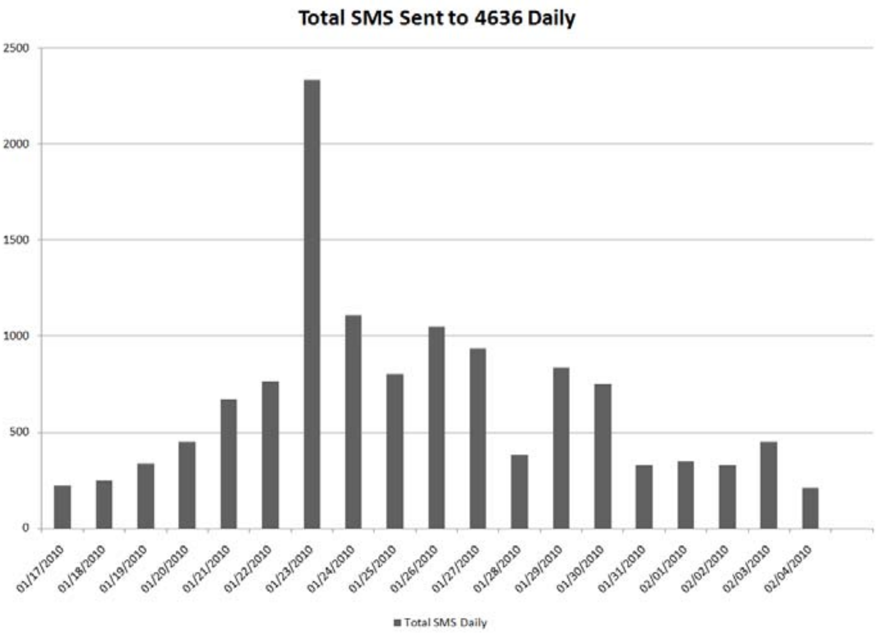

Figure 15. The distribution of the number of messages sent to 4636 daily.

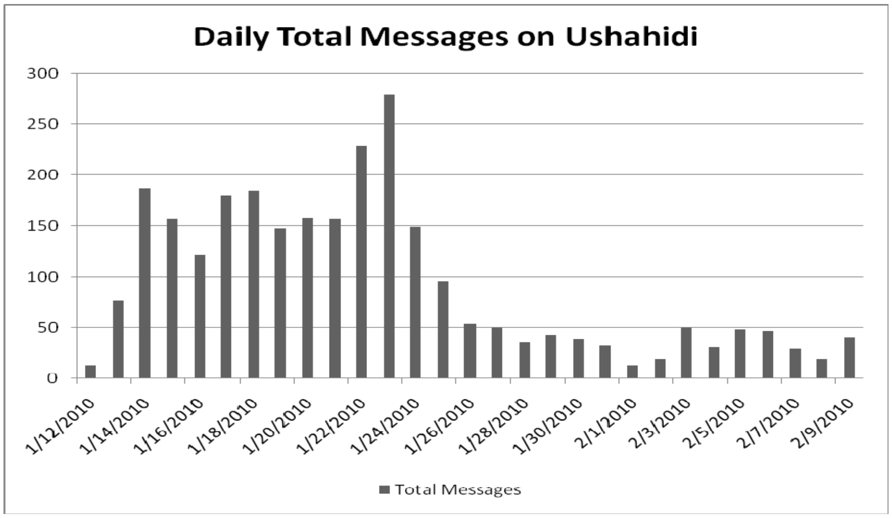

Figure 16. Messages mapped by Ushahidi daily.

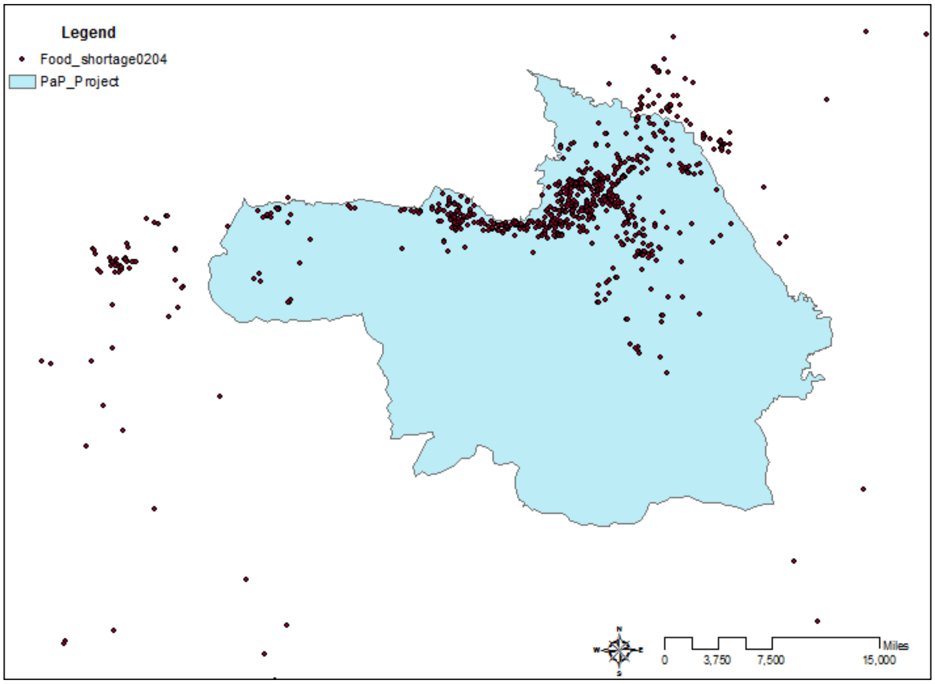

Figure 17. Food-shortage messages around PaP area by 02/04/2010.

Currently it is difficult to verify if messages on Ushahidi have been responded to. There are stories in news and magazines about how Ushahidi help rescue victims (Forrest 2010).

Twitter

The use of Twitter in Haiti earthquake is widely witnessed. The project 4636 is started with a short message on twitter. Another example shows that a Twitter user in Netherland helps two local Haitians meet each other to share food via Twitter (Figure 18).

@apolycarpe MY #name IS DECIUS,where DELMAS 33 ROUTE SILO NUMBER 54 IN A BACK #need #help food and water and security for many people #haiti
1:54 PM Jan 21st via HootSuite

@regelmama Decius can have some food from me (rice, beans and oil) but no water. I don't have money to buy gas to (cont) http://tl.gd/4ltd1
2:12 PM Jan 21st from Twitlonger

Figure 18. Tweets that help two Haitians meet each other.

The integration of hashtag with Twitter service improve the searchability of tweets. Hashtag is words or phrases which are prefixed by a hash symbol (#). For example #haiti and #haitiquake are used to tag tweets on the earthquake. By tracing these predefined hashtags, Tweets can be collected. Next an archive of 9,558 tweets collected by Sahana system is studied. Figure 19 presents the total number of tweets collected.

2,169 tweets (22.7%) have location information, either using coordinates (1,323 tweets, 13.8%) or being tagged by #Loc (846 tweets, 8.9%). Tweets received after January 21st are processed to have category as requests for food, water, medicine, or shelter, and reports on the earthquake. Table 6 shows the number of tweets in each category. And Figure 20 presents the amount of tweets collected in each category after January 21st.

Table 6. The distribution of tweets (after 01/21) in each request category.

	Report	Food_Req	Shelter_Req	Water_Req	Med_Req
Number of Tweets	1703	901	204	142	62
Percentage (%)	17.80%	9%	2.13%	1.50%	0.65%

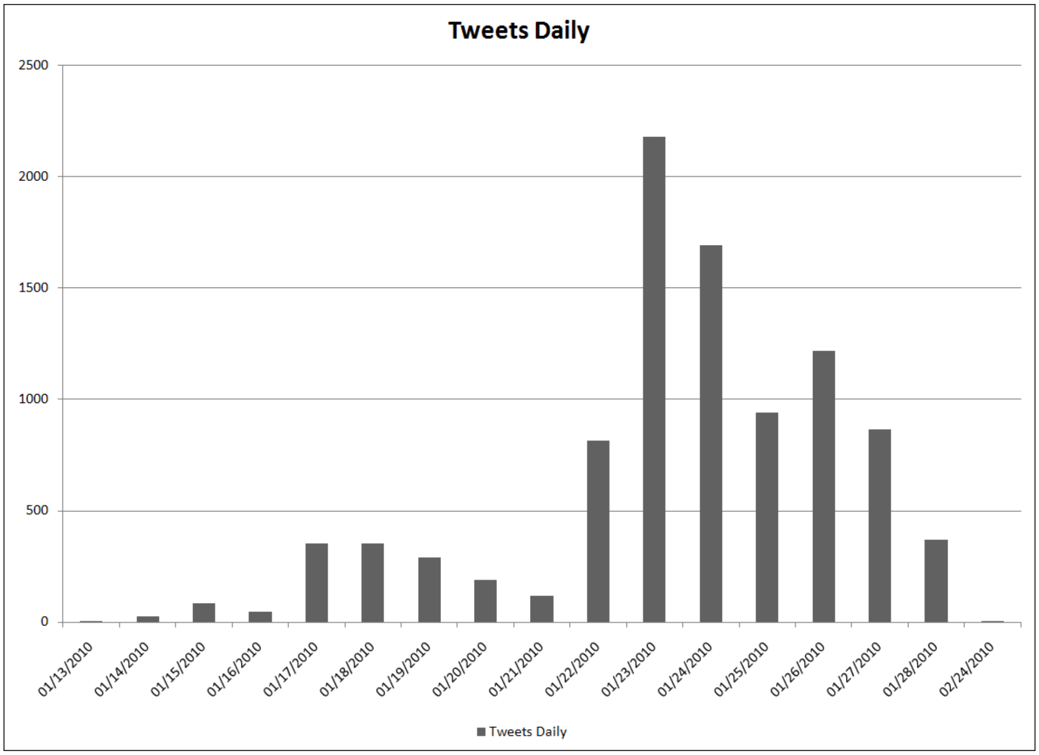

Figure 19. Tweets collected daily by Sahana system.

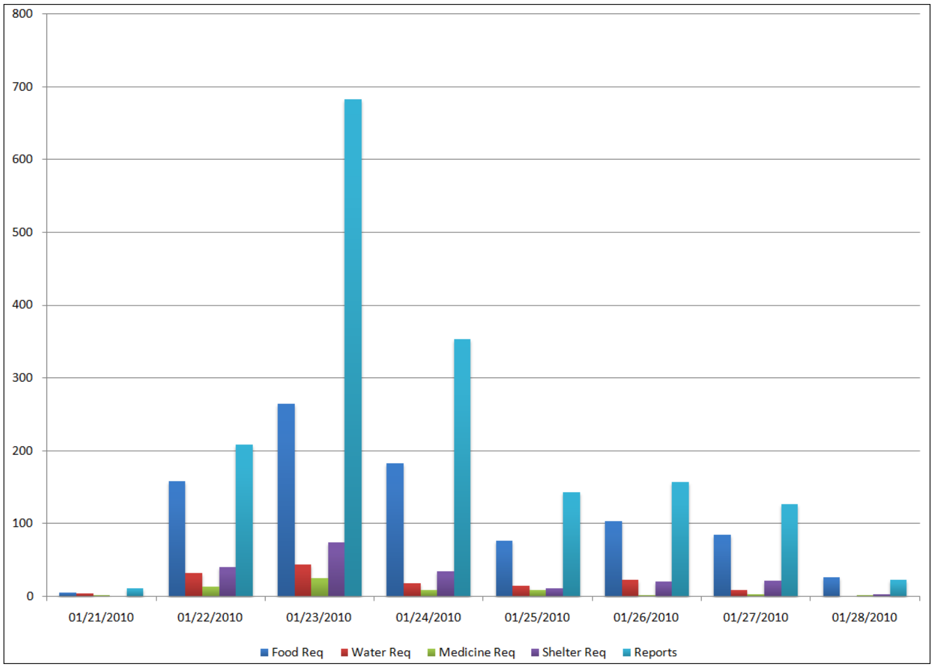

Figure 20. The amount of Tweets in each category collected after 01/21.

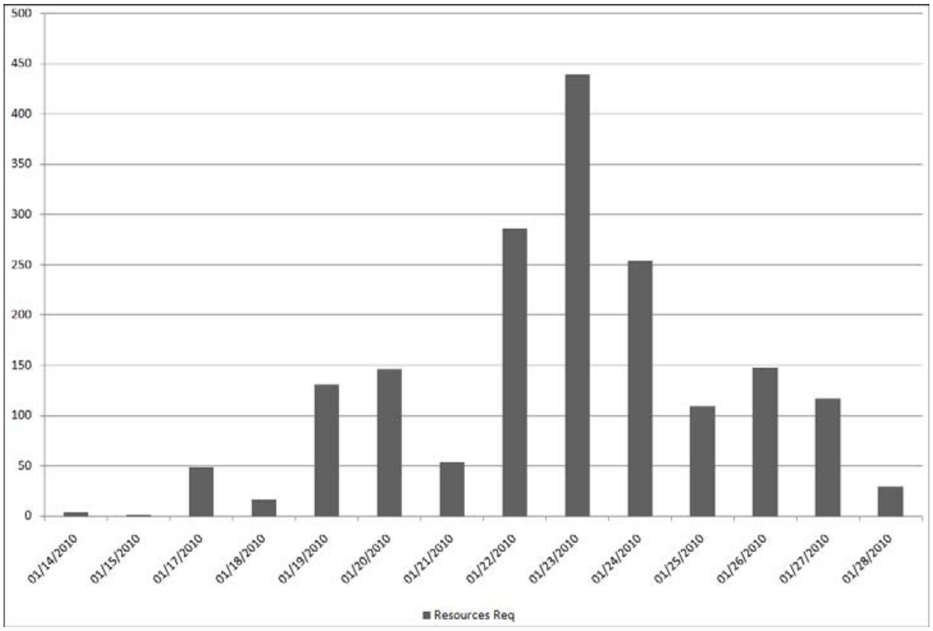

Figure 21. Tweets that request resources.

Before January 21st, tweets are not categorized, and their requests for help can only be detected by the system if they include a #need tag. When include uncategorized tweets, all tweets for resources detected by the system are displayed in Figure 21.

When look at location information of all requests and reports (3,488 tweets), only 1,208 (34.6%) of them have coordinate or #Loc data, which can be detected and processed by machines.

From 2005 to 2010, VGI develops from spontaneous activities to more organized and coordinated operations in humanitarian activities. OSM collaborations with UN has conducted humanitarian mapping in Palestinian West Bank, Kenya, Sudan and many other countries. In Haiti earthquake the OSM community helps create a detailed map of Haiti within several days. The story is commonly reported by mainstream medias. Official medias are not the only conduit for disaster information. Grassroots reports are made through web2.0 services. Photos, videos, blogs, and maps are used. In developing countries where Internet is not widely used by local citizens, a new form of participation has been deployed. Ushahidi is based on the collaboration between mobile phones and a web-based mapping framework. In Haiti earthquake it helps make time critical responses to victims' requests. Ushahidi is also deployed in countries like Philippines, Mexico, India and several African countries. It is also used in the US for purposes like monitoring weather condition, monitoring local crime, and tracking diseases. All these activities are driven by volunteers, who are investigated next.

4.2. Volunteers and Their Collaborations in Producing VGI

In order to use OSM service, a user must at least have a computer that connects to the Internet, which is high speed. Therefore the user can view or map, and if the user doesn’t have a GPS but wishes to contribute efforts to collaborative mapping, the user can extract geographic information from background imagery, upload geographic data collected from other resources, or edit maps produced by others. While most web2.0 services are all web-based and demand high speed Internet. Ushahidi creates a means to connect local communities, where high speed Internet is not widely available, through another platform that is more affordable to the local – mobile phone. The system still needs a computer and high speed Internet as its backend system. The advent of Google Maps and many other web2.0 services around 2005 is accompanied by a leap development in high speed Internet infrastructure.

The change between the 1990s and recent years is the increasing rate of high speed Internet penetration into normal people’s daily life. According to the Federal Communications Commission report (2008), the high speed Internet lines grow from under 4.1 million before year 2000 to over 100 million (as of June 30th) in 2007 (Figure 22).

At the same time the price for high speed Internet connection has dropped dramatically. Like the cost for 1.5 Mbps connection in 2001 was $50 and the same connection speed only cost less than $30 in 2007. The connection speed for a cost of $50 increases about 10 times from year 2001 to year 2007 (Figure 23).

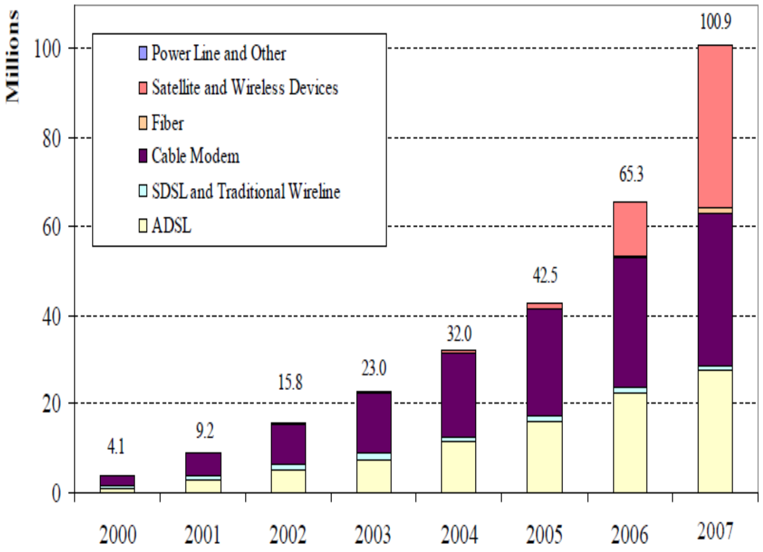

Figure 22. High speed Internet growth[42] from 2000 to 2007.

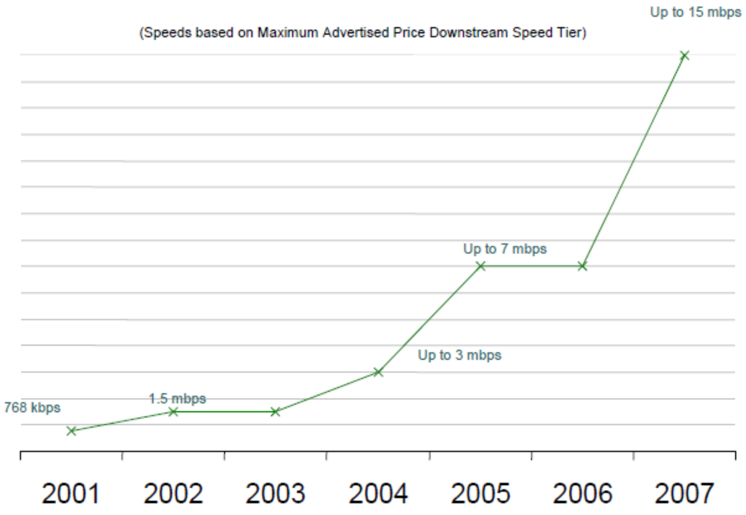

Figure 23. Increasing broadband speeds[43] from 2001 to 2007.

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[42] Source: FCC's High Speed Services for Internet Access Report

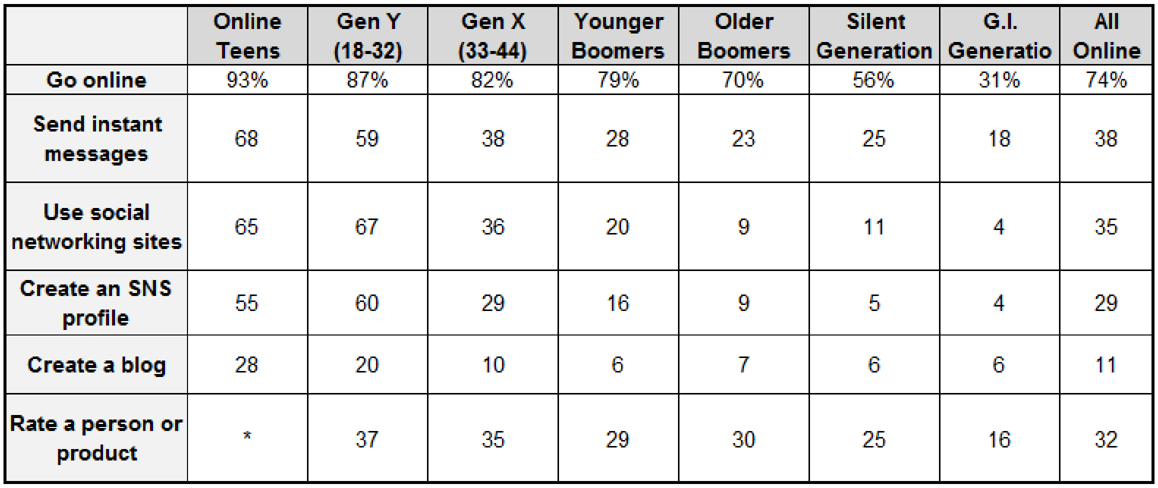
[43] Source: US Telecom 2008.

The constant increasing geographic coverage and decreasing cost of high speed Internet connection support the flourish of rich Internet applications, which include the highly interactive web applications. Therefore the same web applications, such as sharing photos or videos, which are normally of large file size, failed in the 1990s because of the limited availableness of high speed Internet connection and the high cost for downloading large files, and has created unprecedented level of impacts to date.

When taken into consideration of the wireless high speed Internet, the penetration of Internet into our daily lives is even deeper and broader. In the United States, the successful auction of 700 MHz broadband wireless connection has created an open environment for more varieties of consumer devices connecting to Internet (e.g. remotely interact with home appliances from anywhere in the future). At the same time using cell phone for browsing Internet grows fast worldwide. According to the China’s Internet Development Report (2009), only in China there are over 100 million users used their cell phone to browse Internet in 2008, which is a 133% increasement compared to the same figure in 2007. In the United States, web 2.0 applications progressively expand their applicable realm to mobile devices, such as smart phone (e.g. iPhone). Applications such as Plazes let people share their spatial/temporal information with friends in real time, and let them discover who is nearby at a specific time, using location information from GPS or wireless signals.

In U.S., Pew Internet & American Life Project (PI) conducted a series of survey during 2008 and 2009 that help improve understanding of web2.0 users and their activities. According to PI’s report (Jones 2009), users from age 18 to 32 are most likely to use internet for entertainment and as a platform to maintain relationships with friends and family. Generally internet is more deeply integrated with younger generation's daily activities. They are more likely to use blogs to communicate with friends on their daily activities, and keep interacting with friends through social networking services. It is a significantly difference from older generation, who treats internet as another source for information and a different communication tool other than traditional phone. Table 7 presents data that are extracted from the Generation Differences in Online Activities report, and shows only activities that may be involved with producing new information.

Table 7. The generation difference in online activities.



	Online Teens	Gen Y (18-32)	Gen X (33-44)	Younger Boomers	Older Boomers	Silent Generation	G.I. Generatio	All Online
Go online	93%	87%	82%	79%	70%	56%	31%	74%
Send instant messages	68	59	38	28	23	25	18	38
Use social networking sites	65	67	36	20	9	11	4	35
Create an SNS profile	55	60	29	16	9	5	4	29
Create a blog	28	20	10	6	7	6	6	11
Rate a person or product	*	37	35	29	30	25	16	32

The number of adults who have a profile online increases dramatically in four years from 8% in 2005 to 35% in 2008 (Lenhart 2009). Web2.0 services are generally used for personal purposes other than professional purposes.

In China, up to year 2008 China has 298 million Internet users, among them 270 millions are broadband Internet uses. And 117 million people use mobile phones to browse Internet (CNNIC 2009). These facts help explain the wide spread of usages of web 2.0 applications in the 2008 Sichuan earthquake. Internet connected the disaster affected people with families, friends, and the outside world. Photos, videos, and blogs about the earthquake are published online, and through these postings, outside world gains knowledge about the earthquake, and helps allocate relief resources.

Wikipedia closely follows happenings of major disasters. As an example, the first Chinese Wikipedia entry “Wenchuan Great Earthquake” was created by a Chinese living at Taipei, Taiwan, on 07:10 UTC May 12, 2008; and the first English Wikipedia entry “2008 Sichuan Earthquake” was created by a British living closed to the Manchester city, on 07:11 UTC May 12, 2008. When both entries were viewed on February 4, 2009, the Chinese Wikipedia entry has totally 477 contributors making 2,700 edits; and the English Wikipedia entry has totally 1,192 contributors with 4,250 edits. As the sheer number of contributors makes it difficult to geographically locate every contributor, contributors on May 12, 2008 is looked. Geographic information is retrieved from personal information provided by registered Wikipedia users, and physical IP address from unregistered users. Since not every register provides their geographic location, there are unknowns. Based on available information, volunteers from 13 regions or countries made contributions to the Chinese Wikipedia entry, and volunteers from 32 countries contributed to English Wikipedia entry. Figure 24 and Figure 25 present the geographic distribution of contributors on May 12, both maps show contributors with recognizable geographic location. While most volunteers for the Chinese Wikipedia entry come from Hong Kong (22 volunteers), mainland China (19 volunteers), and Taiwan (13 volunteers); the volunteers for the English Wikipedia entry come from more countries, with 65 volunteers from the United States, 14 from the United Kingdom, and 13 from mainland China.

The creation of the entry is by making consensus between users. HistoryFlow is a visualization tool by IBM that can be used to analyze the formation of any text content. Figure 20 shows the growing history of the Sichuan earthquake entry between 00:01 May 13th 2008 and 15:08 May 13th 2008.

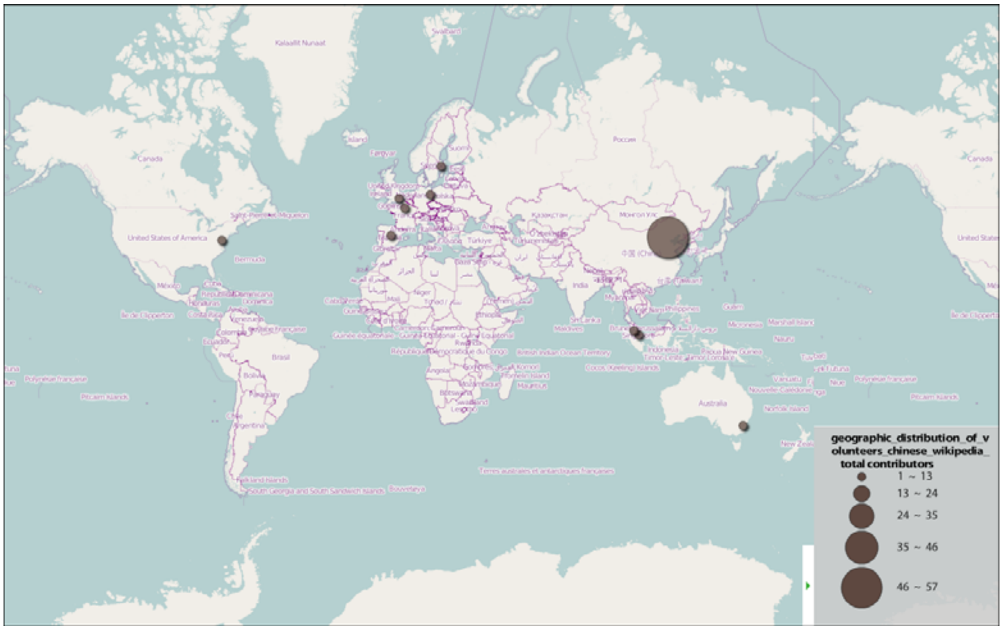
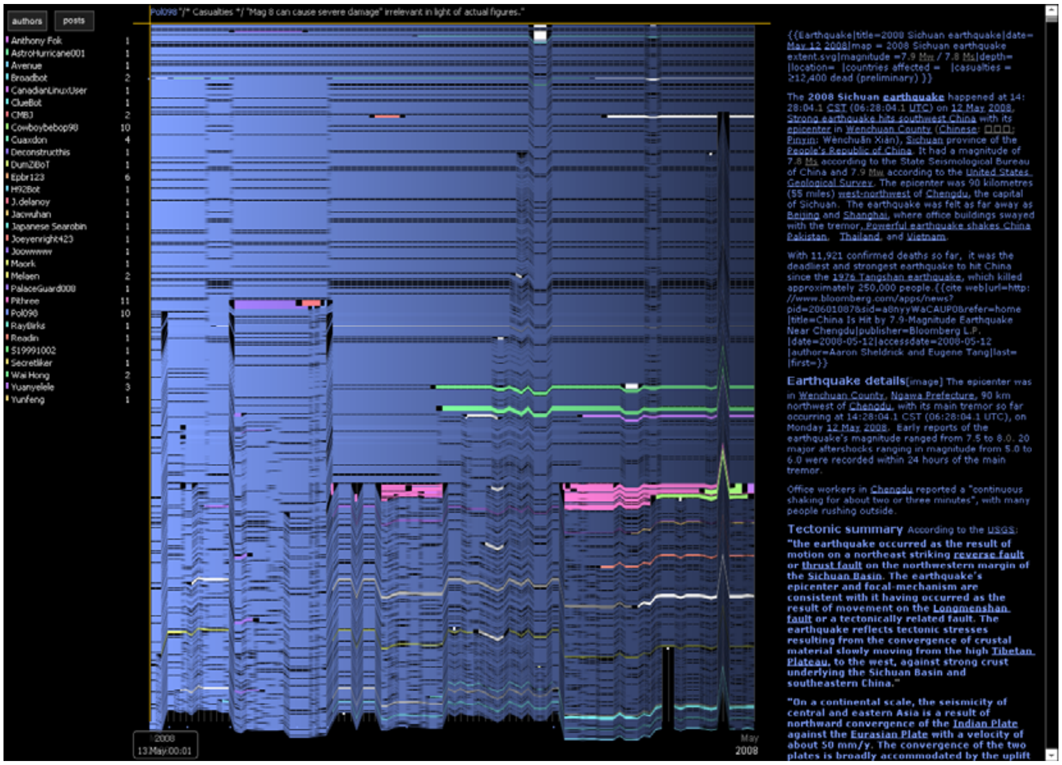


Figure 24. Geographic distribution of contributors of the Wikipedia entry on Sichuan earthquake (Chinese version).

Figure 25. Geographic distribution of contributors of the Wikipedia entry on Sichuan earthquake (English version).



Pol098 "/* Casualties */ "Mag 8 can cause severe damage" irrelevant in light of actual figures."

authors	posts
Anthony Fok	1
AstroHurricane001	1
Avenue	1
Broadbot	2
CanadianLinuxUser	1
ClueBot	1
CMBJ	2
Cowboybebop90	10
Cuaxdon	4
Deconstructhis	1
DumZiBoT	1
Epbr123	6
H92Bot	1
J.delanoy	1
Jacwuhan	1
Japanese Searobin	1
Joeyenright423	1
Jooowwww	1
Maork	1
Melaen	2
PalaceGuard008	1
Pithree	11
Pol098	10
RayBirks	1
Readin	1
S19991002	1
Secretliker	1
Wai Hong	2
Yuanyelele	3
Yunfeng	1

{{Earthquake|title=2008 Sichuan earthquake|date=May 12 2008|map = 2008 Sichuan earthquake extent.svg|magnitude =7.9 Mw / 7.8 Ms|depth= |location= |countries affected = |casualties = ≥12,400 dead (preliminary) }}

The **2008 Sichuan earthquake** happened at 14:28:04.1 CST (06:28:04.1 UTC) on 12 May 2008, Strong earthquake hits southwest China with its epicenter in Wenchuan County (Chinese: □□□; Pinyin: Wènchuān Xiàn), Sichuan province of the People's Republic of China. It had a magnitude of 7.8 Ms according to the State Seismological Bureau of China and 7.9 Mw according to the United States Geological Survey. The epicenter was 90 kilometres (55 miles) west-northwest of Chengdu, the capital of Sichuan. The earthquake was felt as far away as Beijing and Shanghai, where office buildings swayed with the tremor, Powerful earthquake shakes China Pakistan, Thailand, and Vietnam.

With 11,921 confirmed deaths so far, it was the deadliest and strongest earthquake to hit China since the 1976 Tangshan earthquake, which killed approximately 250,000 people.{{cite web|url=http://www.bloomberg.com/apps/news?pid=20601087&sid=a8nyyWaCAUP0&refer=home |title=China Is Hit by 7.9-Magnitude Earthquake Near Chengdu|publisher=Bloomberg L.P. |date=2008-05-12|accessdate=2008-05-12 |author=Aaron Sheldrick and Eugene Tang|last= |first=}}

Earthquake details[image] The epicenter was in Wenchuan County, Ngawa Prefecture, 90 km northwest of Chengdu, with its main tremor so far occurring at 14:28:04.1 CST (06:28:04.1 UTC), on Monday 12 May 2008. Early reports of the earthquake's magnitude ranged from 7.5 to 8.0. 20 major aftershocks ranging in magnitude from 5.0 to 6.0 were recorded within 24 hours of the main tremor.

Office workers in Chengdu reported a "continuous shaking for about two or three minutes", with many people rushing outside.

Tectonic summary According to the USGS: **"the earthquake occurred as the result of motion on a northeast striking reverse fault or thrust fault on the northwestern margin of the Sichuan Basin. The earthquake's epicenter and focal-mechanism are consistent with it having occurred as the result of movement on the Longmenshan fault or a tectonically related fault. The earthquake reflects tectonic stresses resulting from the convergence of crustal material slowly moving from the high Tibetan Plateau, to the west, against strong crust underlying the Sichuan Basin and southeastern China."**

"On a continental scale, the seismicity of central and eastern Asia is a result of northward convergence of the Indian Plate against the Eurasian Plate with a velocity of about 50 mm/y. The convergence of the two plates is broadly accommodated by the uplift

Figure 26. Growing history of the Sichuan earthquake Wikipedia entry.

Each color represents one contributor, and the length of the vertical line is proportionate to the text length that a contributor makes to the entry. Figure 26 reveals that contributors arbitrarily attend the creation of the entry; there are dramatic differences between contributors who started the entry and who help create the final version. And the disappearing color in the graph indicates that contents created by some contributors do not survive the community scrutinizing, and are deleted by other contributors. Figure 27 displays this procedure that a user's edits (Pink color) are edited by others, and only a small portion of the original contributions is kept.

At the same time users do not make equal contributions to the entry. By February 2nd, 2009 there are 1,188 users who edit the Sichuan earthquake entry for 21,655 times. 662 users (55.8%) only make one edit. 1,137 (95.7%) users make no more than 10 edits. Next Figure (28) shows the distribution of users with their total contributions.

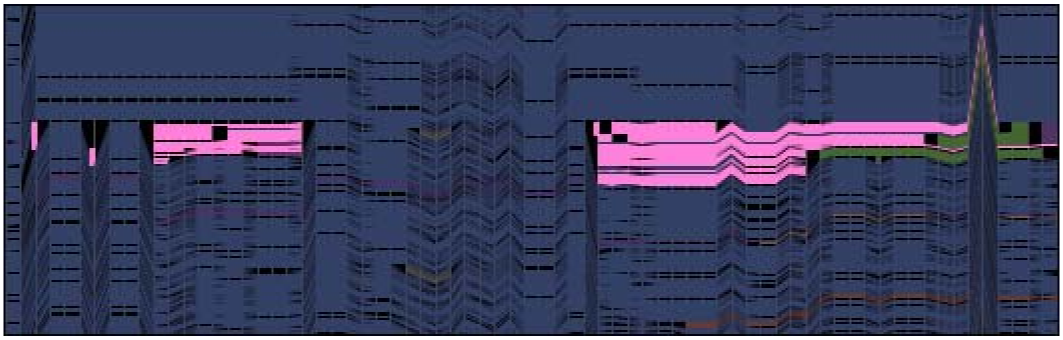


Figure 27. The dynamic procedure of Wikipedia mechanism.

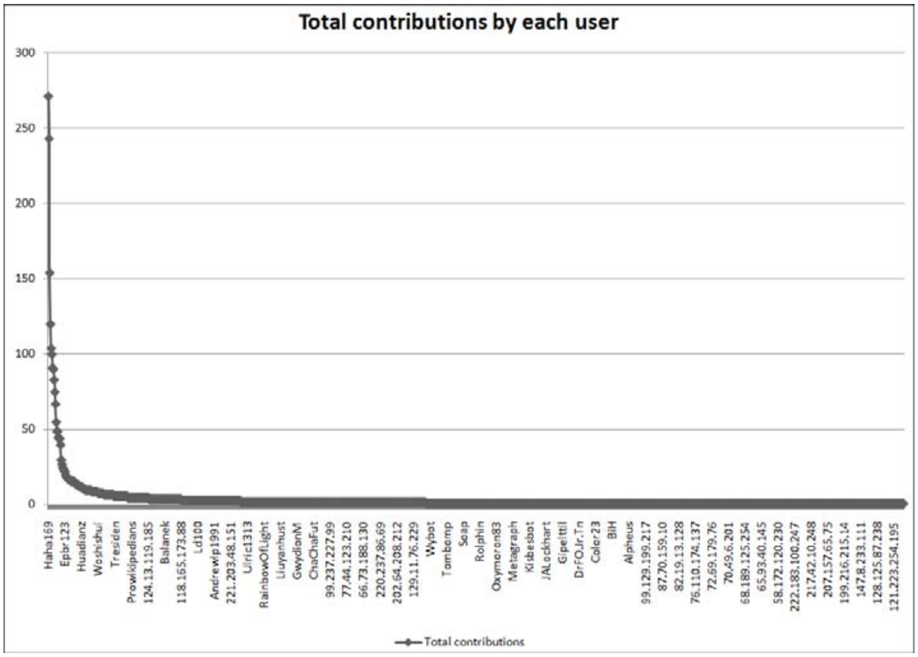


Figure 28. The distribution of users and their total contributions.

The wiki mechanism is adopted by the OSM, which is a wiki world map. Over 200,000 volunteers have contributed to the OSM project, and it is estimated that the number of volunteers would be over one million by August 2010 (Jackson 2010). It is now collaborated with UN and NGOs to carry out humanitarian mapping activities in many developing countries. It created a detailed map about Haiti that help relief organizations conduct operations in Haiti earthquake. The achievement is totally made by collaborations of volunteers. Only for a portion of area of the capital, Port-au-Prince, there are totally 209 contributors.

When OSM users and their contributions are plotted (Figure 29), it shows the same contribution pattern as in many user driven websites. A small group of core users contribute the majority of content, with a long tail of accidental contributors.

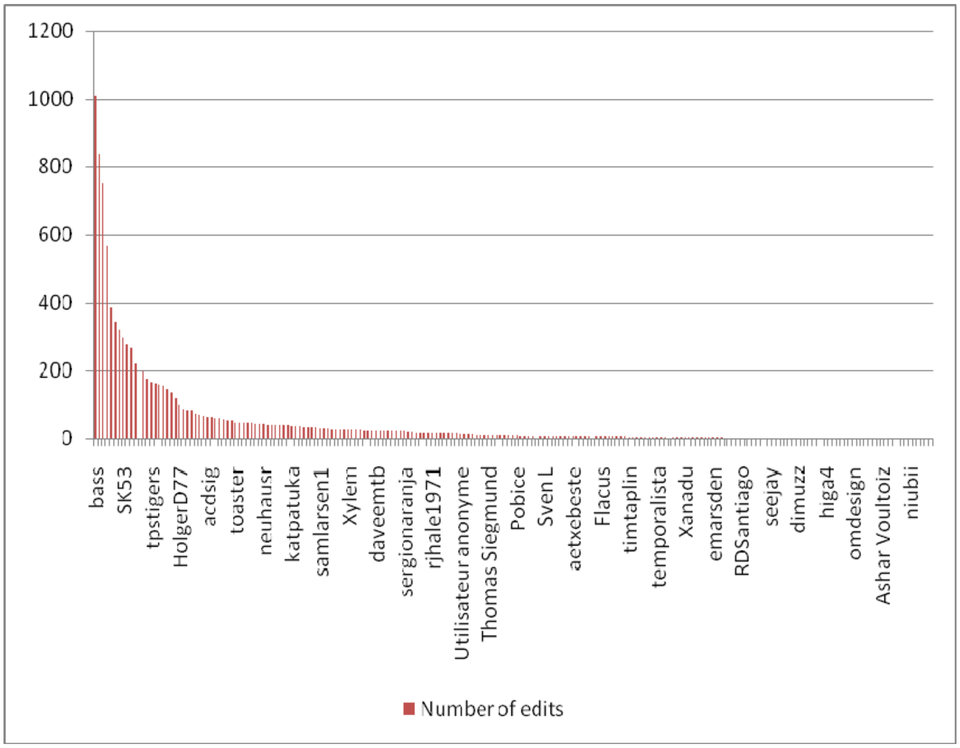


Figure 29. OSM users with their contributions.

Most contributions are made for road information (total number is 5,591 in the study area), beside road features, there is information about buildings (total number is 2,074), gazetteers (total number is 1,731), refugees (total number is 948), land uses (total number is 578), and etc. Remote sensing is one of the crucial technologies that support OSM. Imageries from commercial satellite, which are made public by companies like Google and Yahoo are the backdrops for most volunteers' contributions. For the study areas, 4,145 contributions are claimed to be based on GeoEye, 2,232 contributions are based on Google, and Yahoo is source for 1,246 contributions. Some OSM users, who help create Haiti maps, are registered at the WikiProject Haiti[44]. There are 102

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[44] http://wiki.openstreetmap.org/wiki/WikiProject_Haiti/Who_is_helping

volunteers. By examining their registration information, users' nationalities are identified. 31 users do not provide enough information to decide their nationalities. Figure 30 presents users with their nationalities.

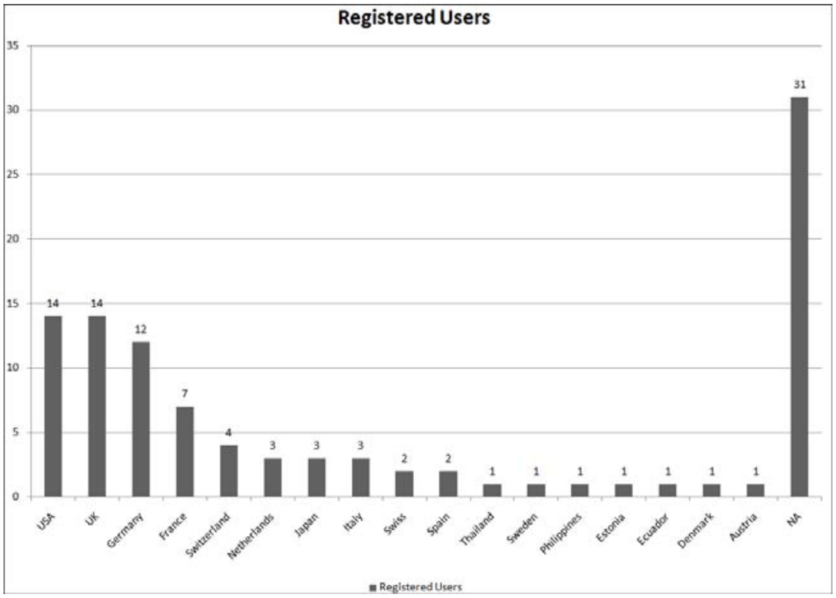


Figure 30. Registered OSM user for Haiti project with nationalities.

In Haiti where geographic information is scarce, people have to rely on satellite imageries for OSM data. In US, where public geographic information is relatively abundant, users can upload data in public domain to improve OSM coverage. The integration of the Topologically Integrated Geographic Encoding and Referencing (TIGER) data dramatically improve OSM coverage in US. OSM data that created from TIGER is special and very different from data that are collected by volunteers using GPS. In the way they are created, OSM data from TIGER are more closely to data that are extracted from satellite imageries. Where satellite imageries are backdrops for OSM data extracted from them, TIGER data are backdrops for OSM data as well. However the difficulty and skills that are required by both methods are not at the same level. Users can easily trace road networks using Yahoo! Maps. In order to trace road network information in TIGER data, users must have computer programming skills and cartographic knowledge. Programs are designed to automatically draw nodes, segments, and ways by tracing TIGER data. Users have to make decisions on how to convert data attributes of TIGER data into tags of OSM. A new set of OSM data are created from TIGER data. However they are not the same data. While it is a fast way to improve OSM coverage, it creates new problems that are discussed later in the quality of VGI. A study on OSM of Houston, Texas area shows that it only requires a small number of users to create OSM data that cover the whole area.

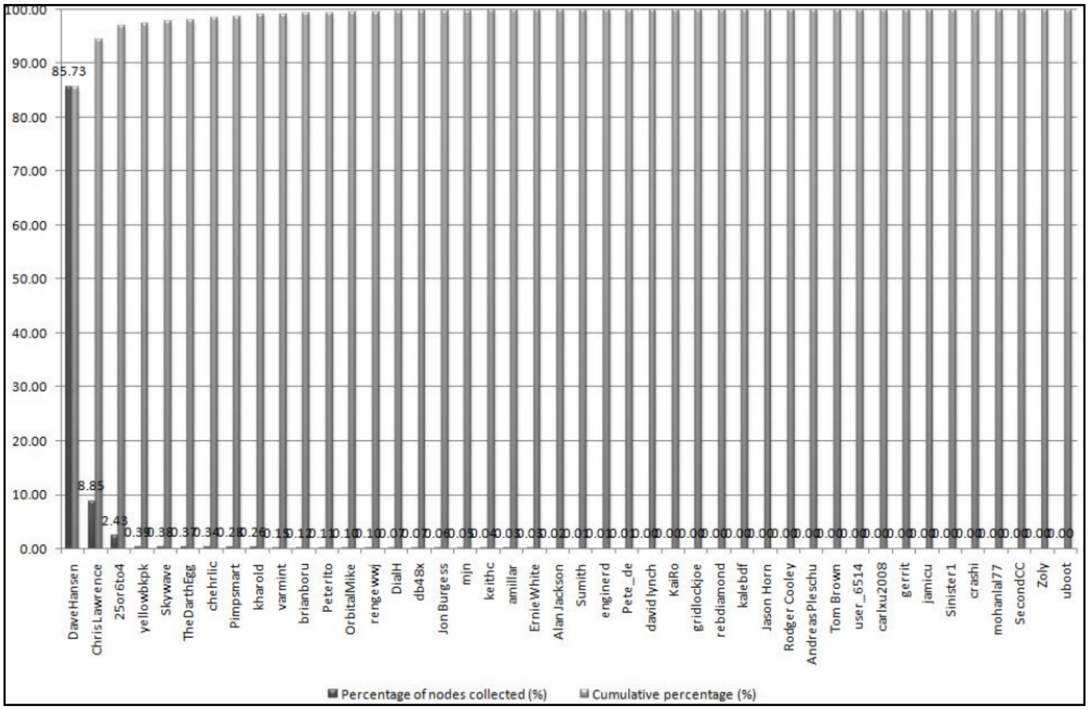


Figure 31. Percentage of nodes contributed by a user and the cumulative percentage.

The nodes dataset is used for the analysis. The number of users contributed to OSM of the Houston urbanized area is counted. There are only 45 users (include Dave Hansen who accomplished most of the TIGER uploading work) in the urban area. Figure 31 shows the contribution percentage of each user to the OSM dataset and the summing up contributions. As shown by the Figure 31, Dave Hansen already contributed 86% data of OSM in Houston urban area.

Next the geographic distribution of users is mapped. The map presents the number of users per sq km (Figure 32). Here the user who help integrate TIGER data is not counted. Therefore users in next map create OSM data either from GPS tracks or from satellite imageries.

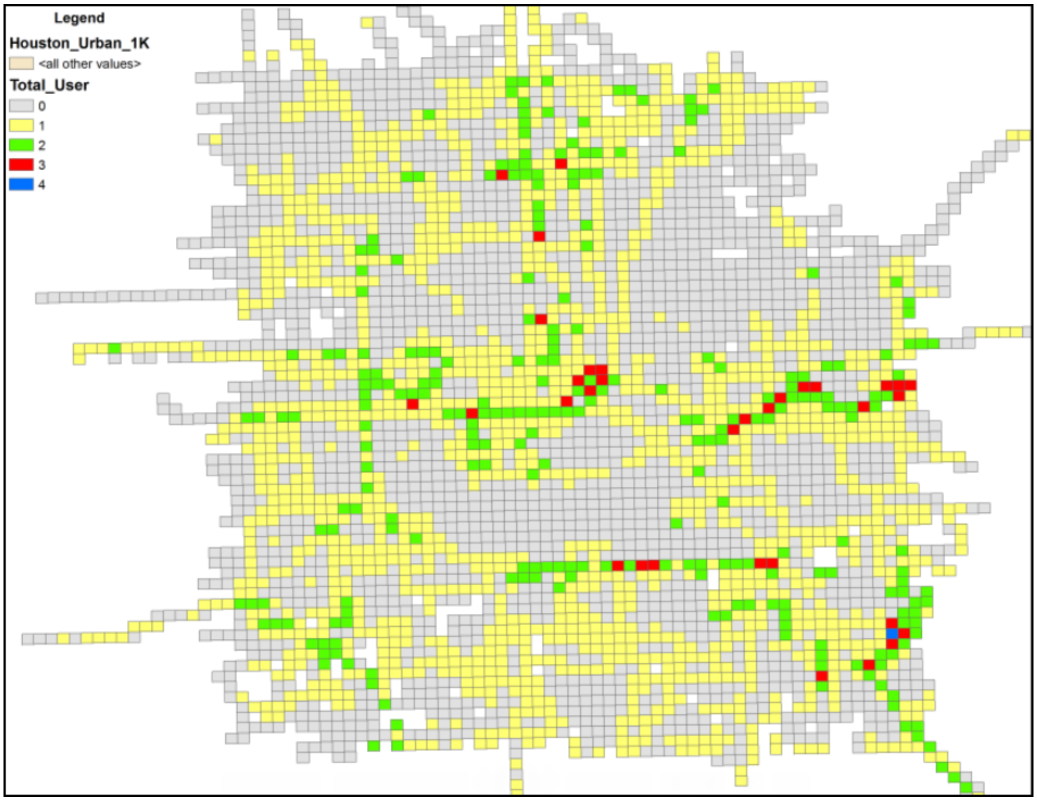


Figure 32. Distribution of users per square kilometer.

The geographic distribution of users is uneven. For most of the area where there are OSM data from GPS tracks or imageries, other than from TIGER dataset, there are only 1 or 2 users who make contributions. Their contributions clustered around major highways. Although TIGER dataset helps improve OSM coverage, the low usership is a serious obstacle to the improvement of overall OSM quality, as errors inherited from TIGER are less likely to be corrected for roads other than major highways.

While VGI is assisting in emergency relief operations, and volunteers are collectively these volunteers are recognized as the “first responders of the wired world”

(Currion 2005). One question is what is the quality of VGI. Next OSM data quality is assessed using OSM data created for the Houston, Texas area and data for the Haiti area.

4.3. Data Quality of VGI

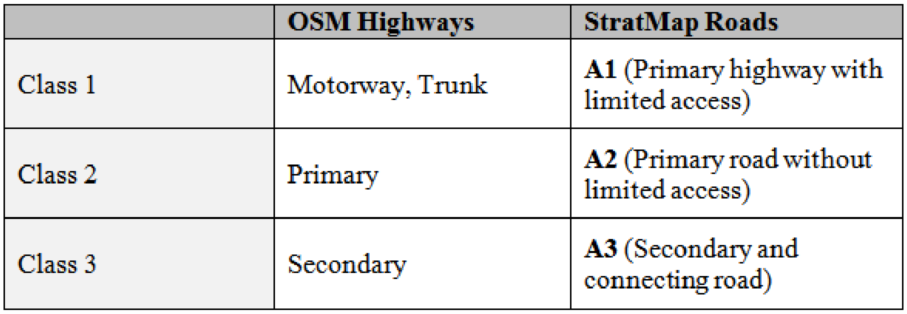
Houston, Texas Area

The study area one includes 5 counties surrounding the Houston urbanized area called Greater Houston. The quality of OSM's highway information is studied. OSM operates in wiki mode, whose information quality is maintained by a mechanism close to the effect of peer review. Eric S. Raymond in the essay 'The Cathedral and the Bazaar' calls it the Linus' Law that 'given enough eyeballs, all bugs are shallow'. Users can upload GPS data, out-of-copyright maps, or public domain data to OSM, or annotate aerial photographs from Yahoo! under the agreement between OSM and the company. OSM data are open to registered users for edits such as correcting errors, adding attribute values, or deleting features. For more information regarding OSM see Haklay and Weber (2008). As Wikipedia articles, which have more editors, are better than those with fewer editors (Wikinson and Huberman 2007; Kittur and Kraut 2008), OSM is expected to improve its quality with more users.

Transportation data from the Texas Strategic Mapping Program (or StratMap) are used as the authoritative data. By implementing 2004 DOQ imagery as references, the second version (Transportation Ver. 2.0) of StratMap transportation data improved spatial quality in urban areas, and 150,000 miles of new roads are added to the datasets comparing with the first version. For the DOQ data, the National Map Accuracy Standards (NMAS) stipulates that 90 percent of check points must not exceed 33.3 feet (about 10 meters) at the scale 1:12,000. Independent studies show that the mean RMS errors for the checkpoints are between 1.7 meters and 3.2 meters depending on the measurement techniques. DOQ was used for improving the quality of TIGER dataset (O'Grady 2001).

OSM data for the study area are downloaded from the CloudMade website (www.cloudmade.com). CloudMade is a third-party service provider that directly utilizes OSM data. The reasons we use data from CloudMade, are first OpenStreetMap website puts restrictions on the download data size, and it takes lots of time and labor to download the whole area in small pieces; second CloudMade offers open APIs to access its web mapping services, by using data from its website, we have understanding of its data quality. The OSM data are last updated on July 08 2009 on CloudMade website when we download. Here we adopt the highway shapefiles converted by the CloudMade. The data have three attributes about the highways: road types, road name, and one-way information. CloudMade strips off OSM user information from its shapefile. In order to study the user information, we managed to download OSM data from its website for the Houston urban area convert the data into shapefile.

Table 8. Classification of road types.



	OSM Highways	**StratMap Roads**
Class 1	Motorway, Trunk	**A1** (Primary highway with limited access)
Class 2	Primary	**A2** (Primary road without limited access)
Class 3	Secondary	**A3** (Secondary and connecting road)

Study shows that during emergency evacuation, major highways especially primary highways are the most relied on evacuation route by evacuees (Dow and Cutter 2002). In this study the quality of OSM's major highway data is focused besides the quality of the overall OSM highway data.

OSM uses tags to define classes of roads. All road features share the key "highway", and by assigning different values (e.g., motorway, truck, or primary) to the key, roads are classified into different classes. StratMap transportation dataset uses the Feature Class Codes (FCC), which group roads into 8 classes (A00 – A09 road classifications are not used). In order to assess the OSM quality for evacuation purpose, major highway roads are divided into three classes. The classification and corresponding relationships between both dataset are shown in Table 8.

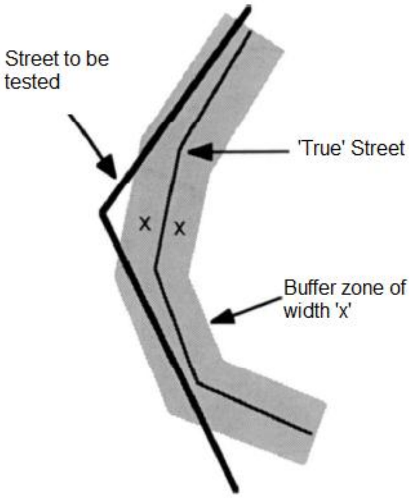


Figure 33. Positional accuracy assessing method modified from Goodchild and Hunter (1997) and Hunter (1999).

Positional accuracy

The method to assess the positional accuracy is developed by Goodchild and Hunter (1997) and Hunter (1999). First buffers are created for StratMap dataset then calculates the percentage of line features from OSM that fall inside of the buffers of the StratMap dataset (Figure 33). Here StratMap dataset is assumed to represent the actual position of road features. The buffer width (x) is 10 meters.

A control framework with a lattice of cells is imposed for the result map. The grid layer consists of 1-kilometer by 1-kilometer rectangle cells. The tessellation of cells provides the spatial control for measuring the overlapping ratio. The overlapping ratio is calculated by ratio = (OSM overlapping StratMap area) / (OSM area). The positional accuracy for all OSM highway data is shown in Figure 34. The comparison result is in Table 9.

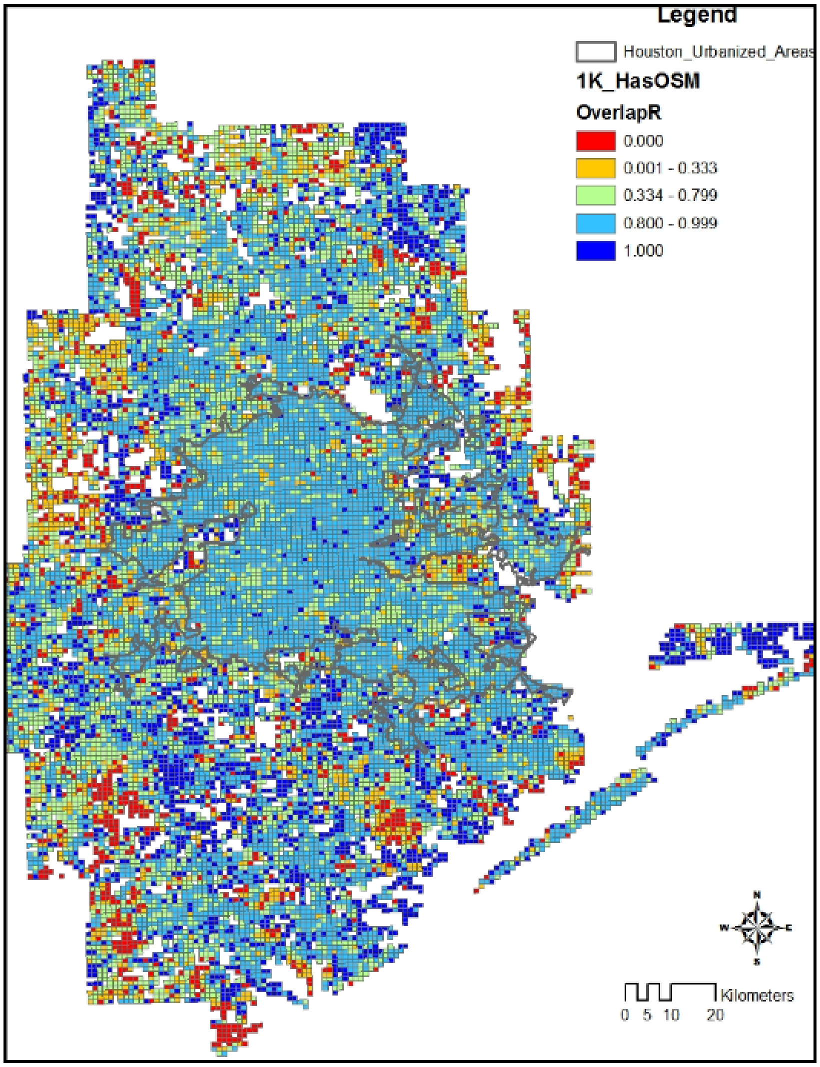


Figure 34. Positional accuracy of all OSM highway data.

Table 9. Positional accuracy of all OSM roads.

Overlapping ratio	Percentage of grid cells (%)
0 (Red)	7.12
0 - 0.333 (Yellow)	8.63
0.334 - 0.799 (Green)	27.78
0.8 - 0.999 (Light blue)	41.36
1 (Blue)	15.11

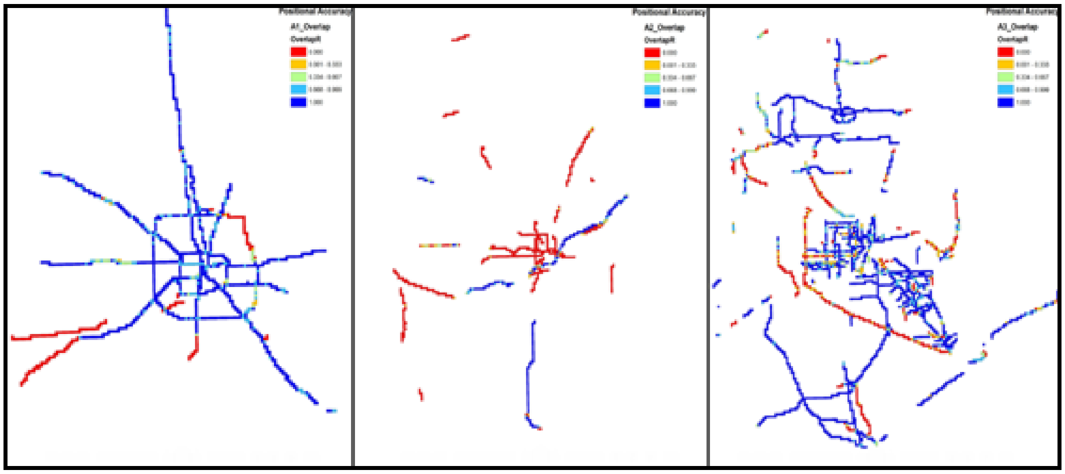


Figure 35. Positional accuracy of major highway roads (Left to right: Class 1, 2, 3).

Table 10. Positional accuracy of the major highway roads.

Overlapping ration	**Percentage of geographic area (%)**		
	Class 1	**Class 2**	**Class 3**
0 (Red)	14.83	65.81	16.01
0.001 - 0.333 (Yellow)	0.95	4.01	6.59
0. 334 - 0.799 (Green)	5.25	2.89	7.14
0.8 - 0.999 (Light blue)	14.41	2.73	8.83
1 (Blue)	64.56	24.56	61.43

For major highway roads, the positional accuracy result is mapped in Figure 35. Table 10 summarizes the percentages of cells in each class. As the results show, OSM provides better positional representation for StratMap A1 and A3 roads than the A2 road.

Completeness

The same control framework is applied for summarize the length difference between OSM dataset and the StratMap dataset using the equation: (Length Difference) = (Length of OSM) – (Length of StratMap). Next map presents the overall length difference between two datasets (Figure 36). Inside the study area, the total road length of the OSM is 62,838,176 meters, and the StratMap is 63,627,630 meters. The total road length of OSM is 98.76% of the StratMap, which indicates at the macro level, OSM data are almost as comprehensive as StratMap.

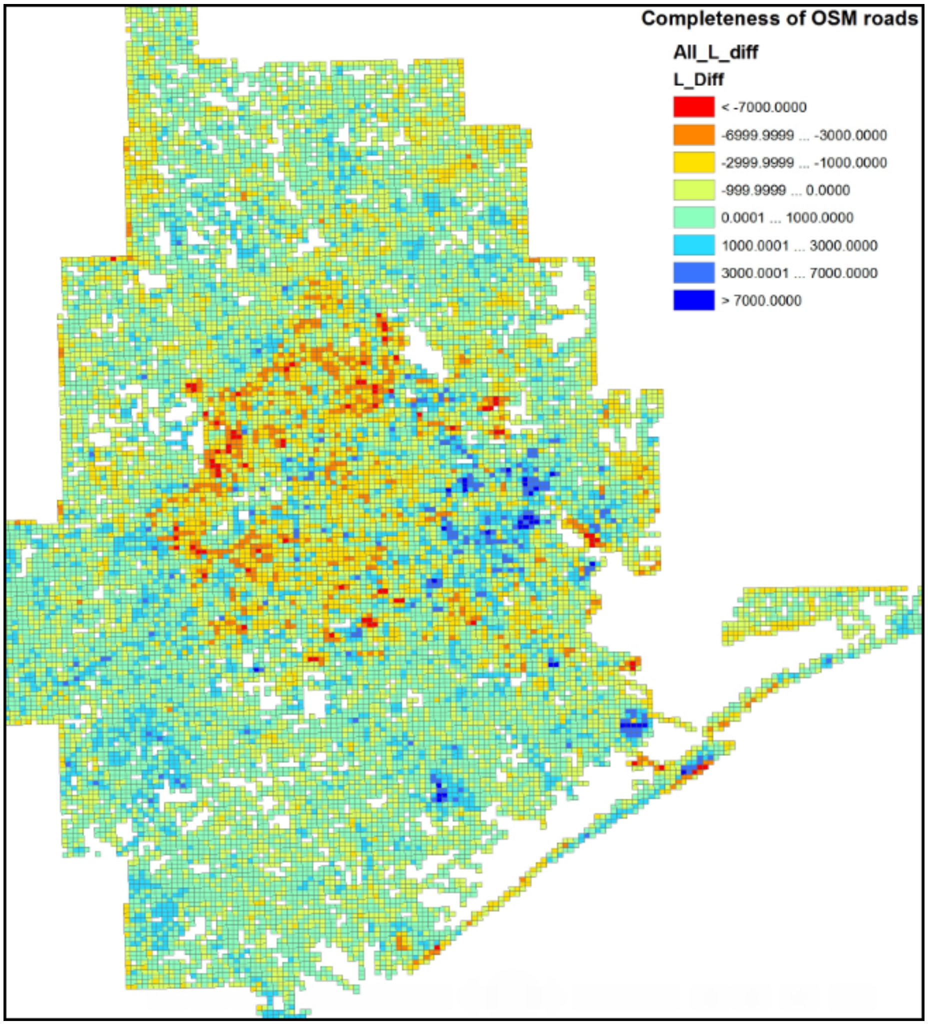


Figure 36. Overall length difference between OSM and StratMap.

Table 11. Length comparison: OSM and StratMap.

Empty cells	1905 (10.24%)
StratMap more detailed than OSM	7383 (39.69%)
OSM more detailed than StratMap	9314 (50.07%)
Total	18,602

There are 1,905 sq km areas with neither StratMap nor OSM features. It covers 10.24% of the study area. Out of the remainder, for 9,314 sq km areas (55.78%), OSM has better coverage than StratMap. See Table 11 for the results.

Considering the fact that the first phase of StratMap was completed in 2001, and since then it has been maintained and enhanced with tremendous investment. OSM only exists for five years, and only three years since it hit the road of the U.S., its achievement is impressive. OSM made this achievement by harnessing collaborations from massive volunteers.

Next the completeness of OSM major highway data is assessed (see Figure 37). Major highway provides capacity for evacuees to escape hazardous zones. Thus information quality about highway system is crucial for planning evacuation routes, and estimating evacuation time. As road types are taken into consideration, attribute quality is an influential factor, for OSM roads not tagged as major highway are excluded.

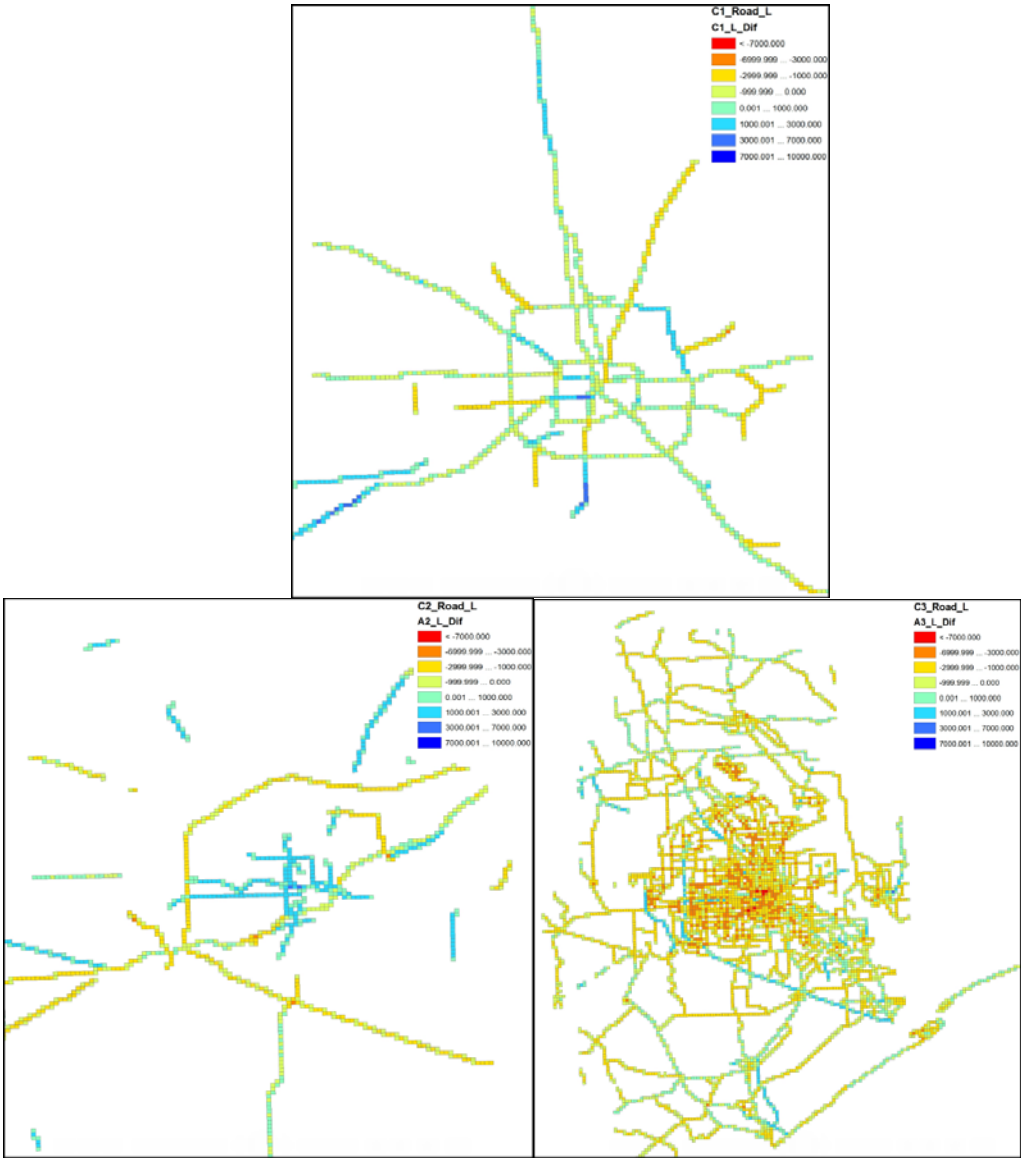


Figure 37. Road length difference between major highway roads (Top right to left: Class 1, 2, 3).

Table 12. Road length difference between both datasets.

	Class 1	Class 2	Class 3
OSM more detailed than StratMap	523 (47%)	486 (48%)	870 (16%)
StratMap more detailed than OSM	588 (53%)	530 (52%)	4643 (84%)
Total	1,111	1,016	5,513

Table 12 summarizes the major highway road length difference between the OSM dataset and the StratMap dataset.

Attribute accuracy

Generally there are two groups in testing attribute accuracy (Chrisman 1991). The first group tests the accuracy of attribute with continuous scales using mathematical models. The accuracy of a relief surface is an example of the first group. The second group tests the accuracy of categorical attributes. The traditional land use inventory is an example. In our study we test the categorical accuracy of highway roads. The test only examines roads with clearly defined codes. StratMap transportation dataset uses Feature Class Codes (FCC) to categorize roads. OSM implements user-defined tags for road types. Although OSM provides guidelines on how to define road types, it is not obliged. All road names of StratMap data are thoroughly inspected to guarantee that names are unique for a road. ‘Driveway’ and ‘Unnamed Street’ are used for multiple roads, together with roads with empty name field, they are grouped together.

For all StratMap road features, about 15% roads are without a proper name, however all their road types are clearly defined and have a FCC value. About 43% of OSM roads are without a name and 0.7% road types are unclassified or undefined. Here we compare the major highway roads defined by OSM to their StratMap counterparts. The first map (Figure 38) is made from StratMap data, and the second map (Figure 39) from OSM data.

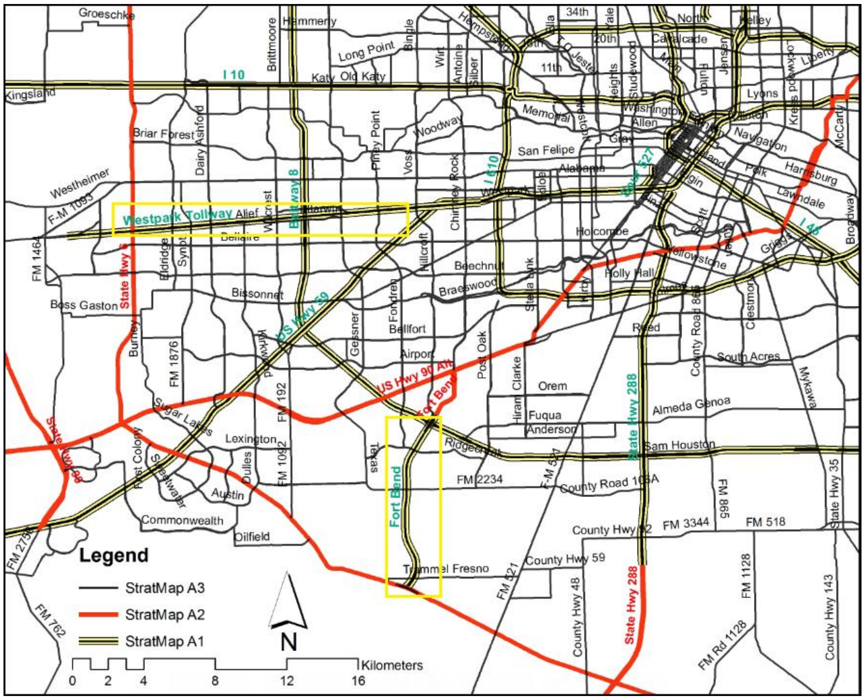


Figure 38. Major Highway roads from StratMap.

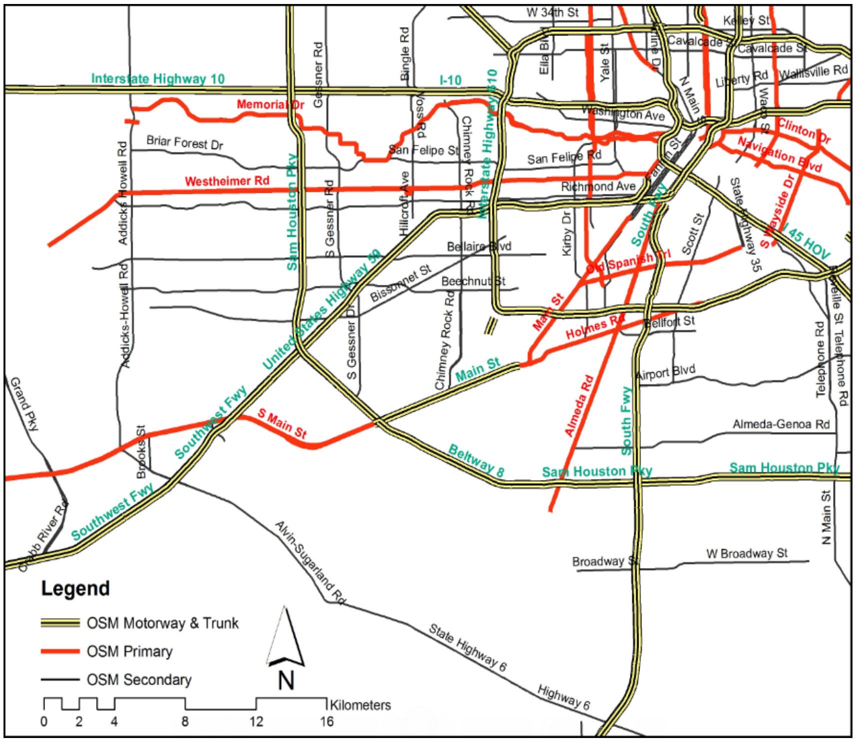


Figure 39. Major highway roads from OSM.

There are obvious disparities between the two maps. For the A1 StratMap highway and OSM Motorway they are much similar, except WestPark Toll-way and Fort Bend are not shown on the OSM map. Many A2 highway roads in StratMap are mistakenly tagged as Secondary highway in OSM. And most StratMap A3 highways are missing from the Secondary highway of OSM, as the counterparts are tagged as “residential” in OSM.

This inaccuracy in attribute greatly biased the previous positional accuracy and the completeness assessments of OSM dataset. Taken the Motorway of OSM as an example, its counterpart in StratMap is carefully picked. So only the same roads in two datasets are compared. 77% of the road length differences are within 100 meters, and 76% of the OSM roads overlap StratMap road precisely (overlapping ratio=1). For the other two highway groups, the biases are even greater caused by the inaccurate road type.

When look at the geographic distribution of unnamed road features (Figure 40), they are widespread across the whole study area.

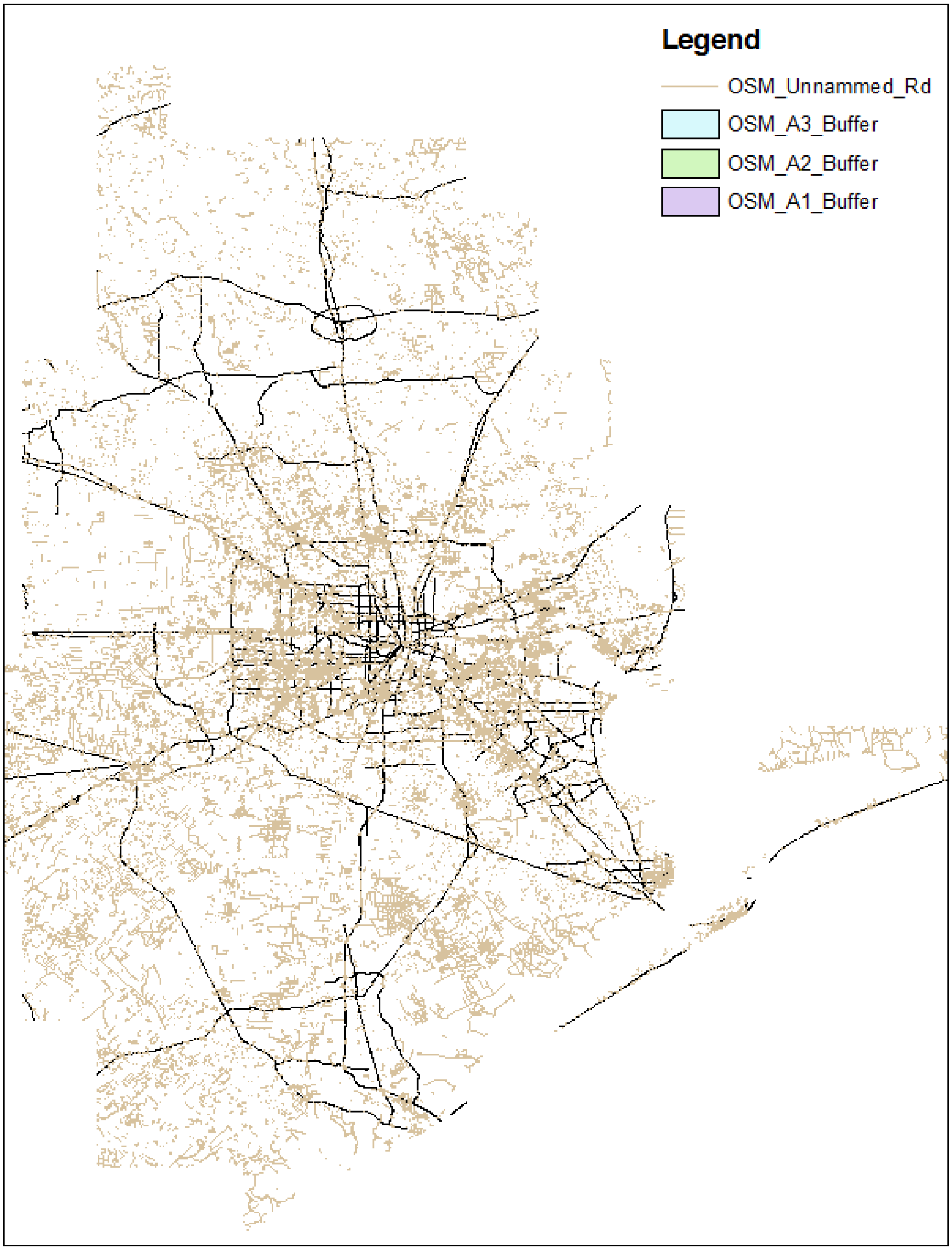


Figure 40. Widespread of unnamed road features in OSM Houston.

Haiti Area

The reference source selected is road information produced by the United Nations Stabilization Mission in Haiti (MINUSTAH). On January 18, MINUSTAH released the GIS data and maps. Even with the existence of official data, UN disaster relief organizations and other emergency management organizations find that OSM data are valuable for managing operations. UN operations are centralized on the Port-au-Prince (PaP) area, and outside the area, there are few geographic data. OSM has better overall coverage in Haiti. In the aftermath of Haiti earthquake, most relief efforts are focused on the PaP area. In order to answer why OSM data are helpful in Haiti. Next, OSM data's positional accuracy, completeness, and attribute accuracy are assessed.

Positional accuracy

In order to support effective emergency decision-making, not only completeness is important, but also the positional accuracy of road information. Two maps in next Figure (41) visually display the positional accuracy of the primary and secondary roads data, when compared to MINUSTAH data.

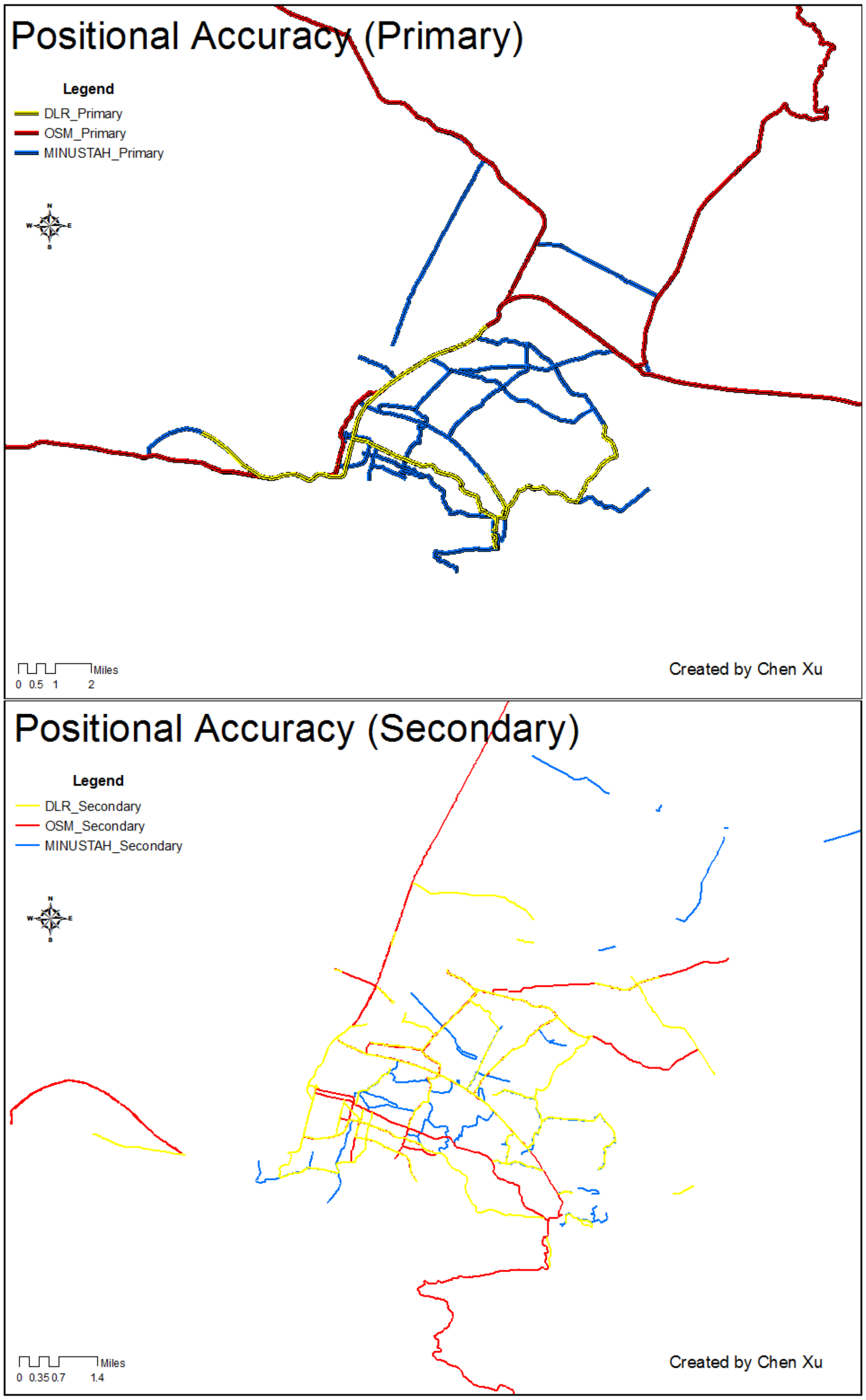


Figure 41. Positional accuracy of the OSM primary and secondary roads data.

For major roads, OSM data have satisfying positional accuracy. And there is obvious differences in road classification. Therefore positional accuracy measurements are affected by the attribute accuracy.

Completeness

Figure 42 shows the overall length difference between OSM and MINUSTAH data.

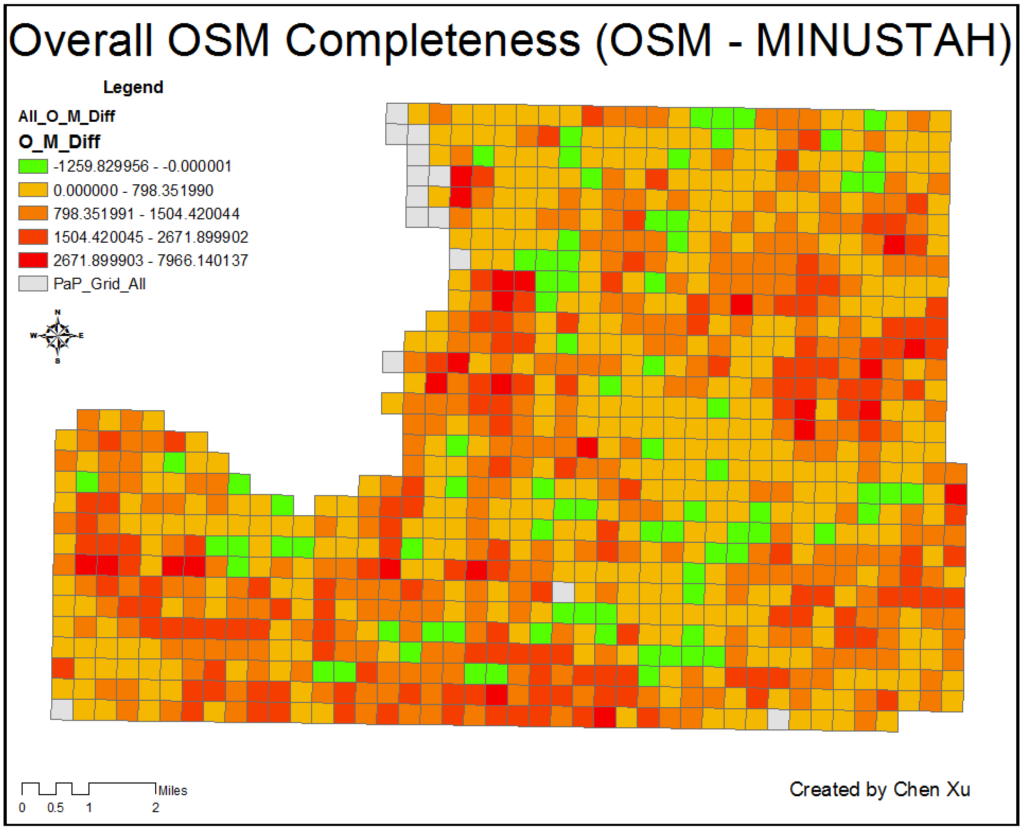


Figure 42. Overall OSM Haiti road data completeness.

It clearly shows that OSM data have better completeness than the UN data. This is due to that more local roads are collected by OSM. OSM data are used for geocoding emergency messages send by local Haitian people. Only OSM data that are properly named can be used for the process. Figure 43 shows the length difference between named OSM and MINUSTAH data.

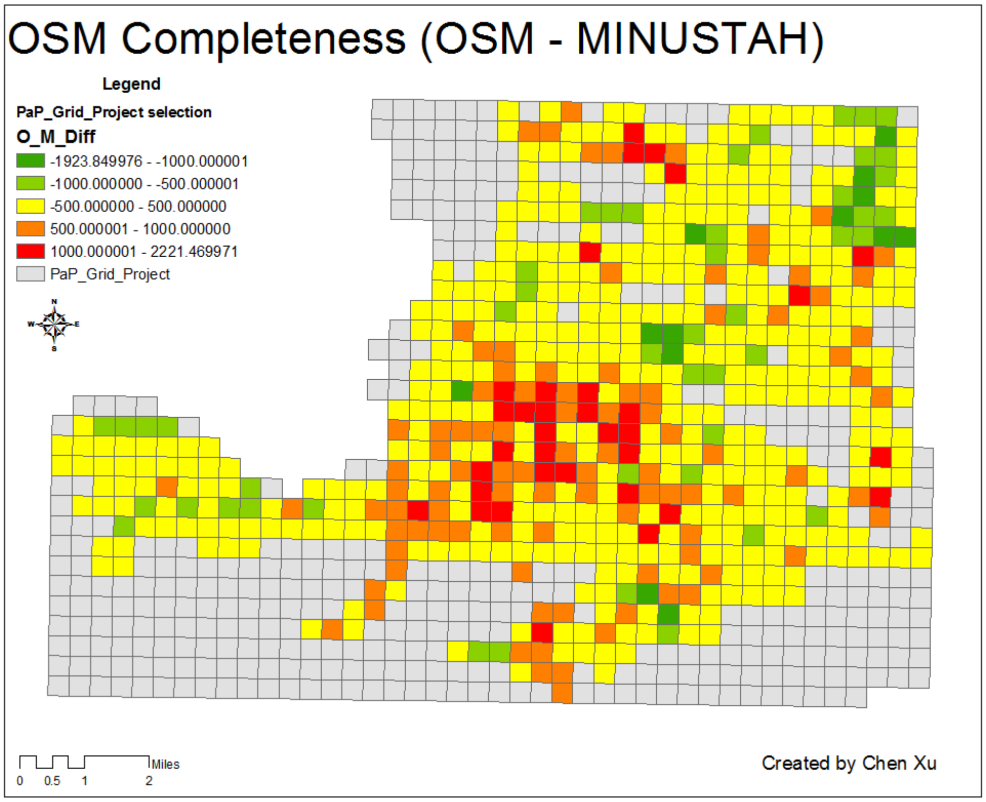


Figure 43. Completeness of named OSM road data.

For the central area, where the earthquake caused the most damages, OSM has better completeness, which can help geocode more emergency messages.

Attribute accuracy

The primary and secondary roads defined by MINUSTAH are illustrated by maps in Figure 44. In contrast to the MINUSTAH data, OSM data show less accurate road classification.

It reveals a fact that although some geographic features like geometry and positions can be extracted remotely, local knowledge is crucial to improve VGI quality. As most Haiti OSM data are extracted from remote sensing imageries or imported from official data by many volunteers, who are not familiar with Haiti before the earthquake, attribute data such as road types and street names are difficult to be collected. Next, 11 datasets are collected, which cover date from January 15 to January 23, January 26, and April 10. Haiti’s level one administrative boundaries are used to assure all datasets are within the same boundaries. Figure 45 presents the increasing road features of OSM Haiti as well as the features without names.

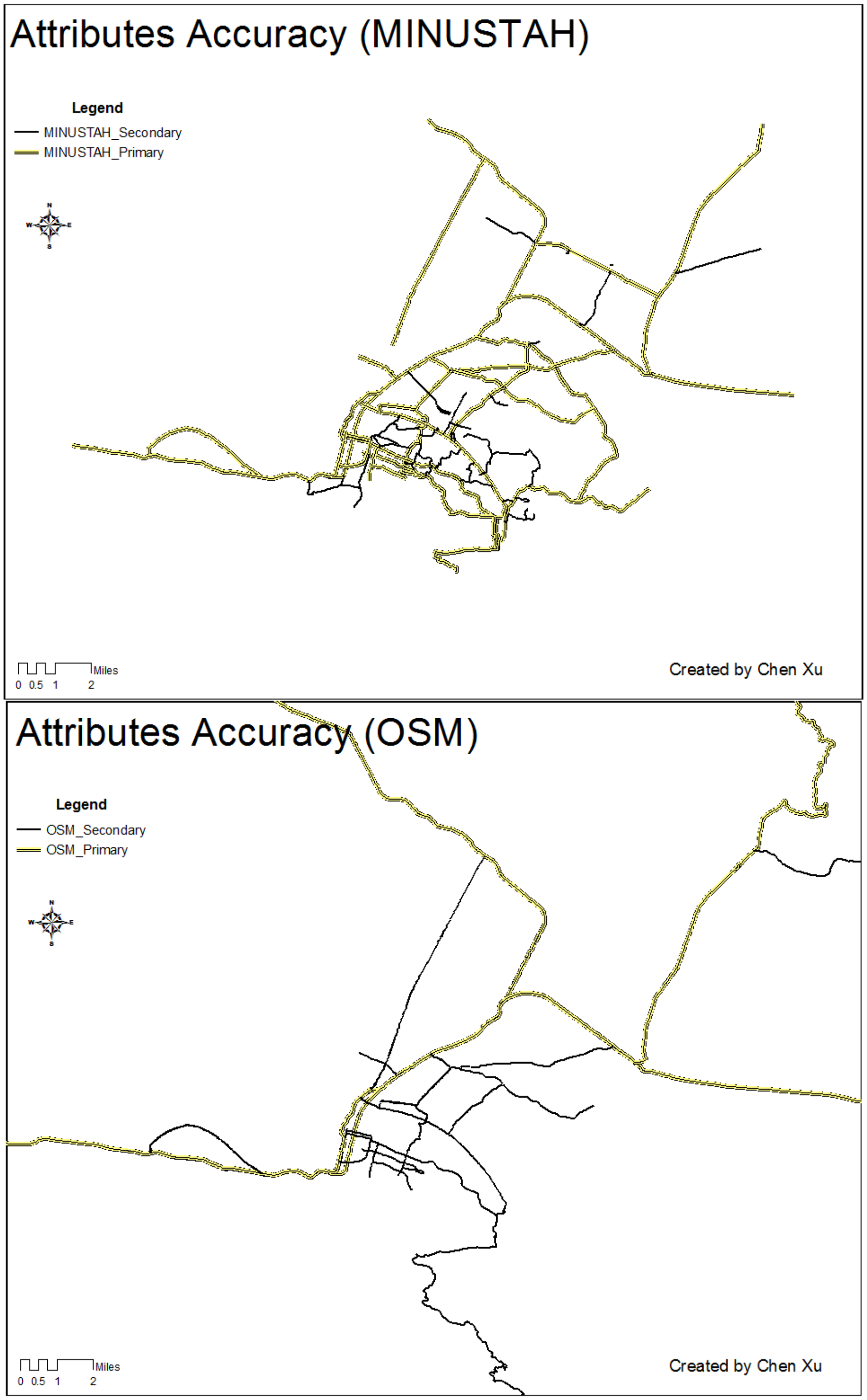


Figure 44. OSM data attribute accuracy.

The results clearly reveal that local knowledge is not well captured by the OSM community. Street names are missing from most of the road features. A natural question would be if such a dataset good for emergency operations? The answer is depends on the geographic location of the mission and the type of the mission. For most of the streets that are named are in the PaP area (Figure 46). Then 74.6% of SMS messages of food shortages and 76.6% of SMS messages of water shortages are within the 100-meter range of named streets. Therefore OSM map can be used for response to more than 70% of requests for resources.

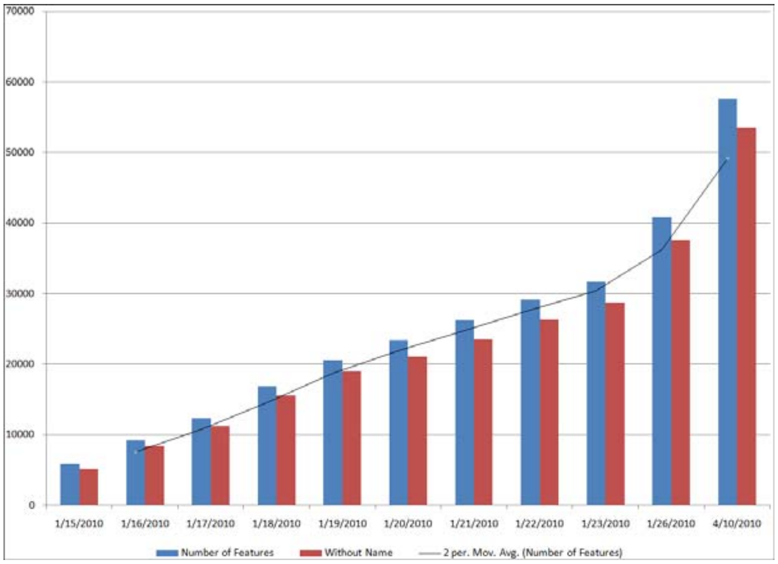


Figure 45. Increasing road features of OSM Haiti and unnamed features.

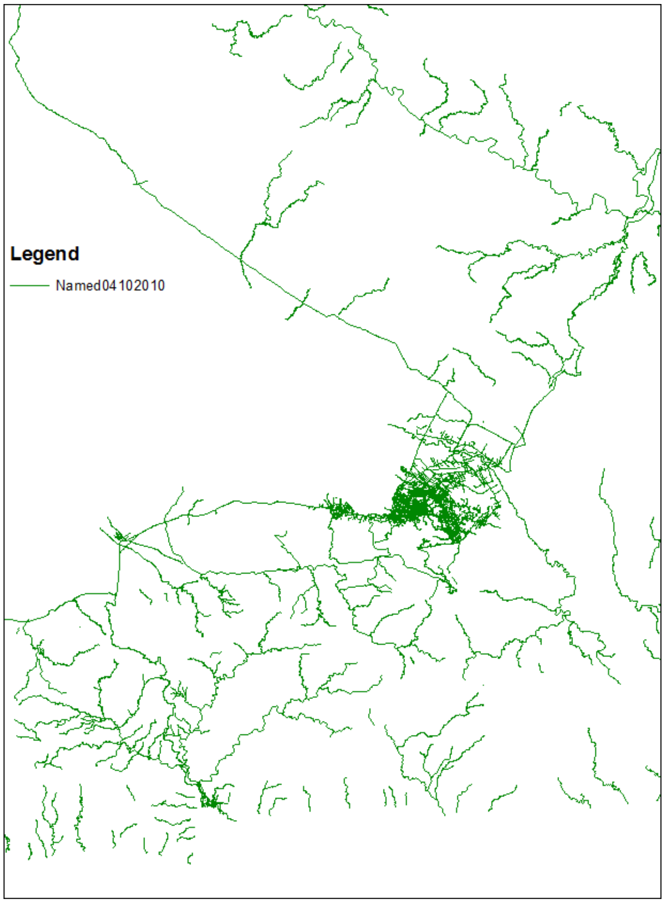


Figure 46. Spatial distribution of named OSM Haiti road features.

OSM road data quality indicator

The benefit of unifying completeness measurement and positional accuracy measurement is that it provides an intuitive and convenient way to quickly assess where OSM data can be used for support decision-making. Next map (Figure 47) displays OSM data quality indicated by indicator 1. In the above map only named roads are included. The results are grouped into four categories (Table 13). Table 14 shows the percentages of grid cells in every category. As illustrated by the results that in areas where there are OSM data, the data quality of OSM is acceptable to high for supporting decision-making.

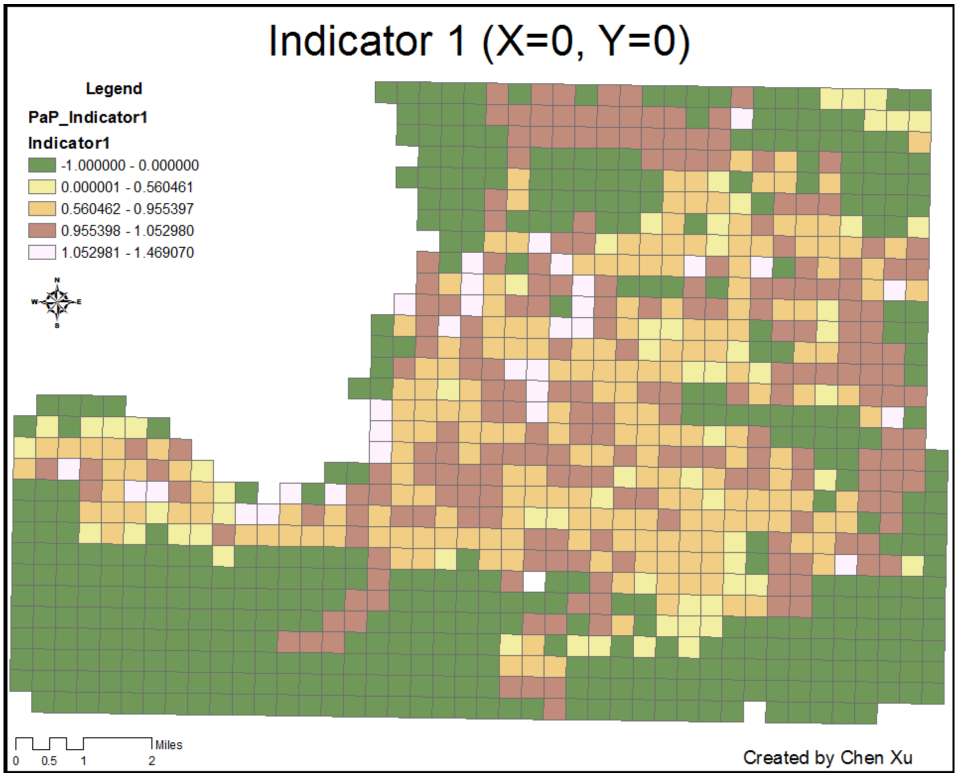
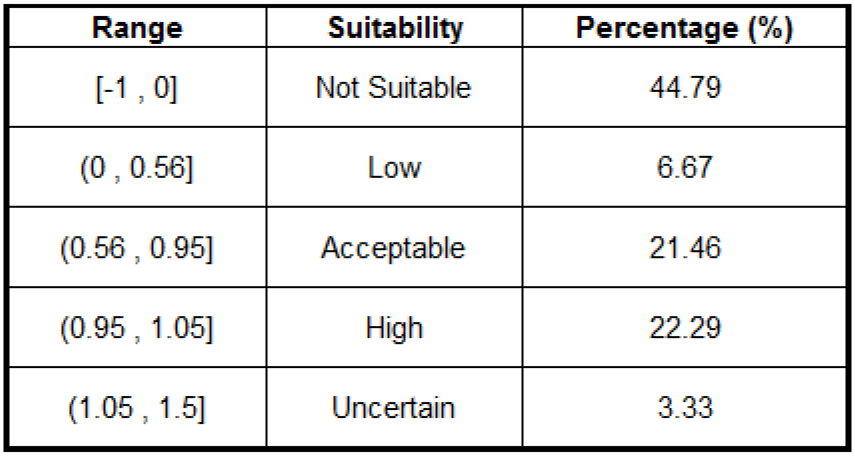


Figure 47. OSM data quality indicator 1 (x=0, y=0).

Table 13. OSM DQ indicator categories.

Indicator Category	Range	Situations	Suitability
1	[-1 , 0]	Completeness is too low. No OSM data.	Not Suitable
2	(0 , 0.56]	Completeness is low. Positional accuracy is low.	Low
3	(0.56 , 0.95]	Completeness is low, but positional accuracy is acceptable. Completeness is acceptable, but positional accuracy is low.	Acceptable
4	(0.95 , 1.05]	Both completeness and positional accuracy are acceptable.	High
5	(1.05 , 1.5]	OSM length >> Reference length, and positional accuracy is acceptable.	Uncertain

Table 14. Percetages of grid cells in every DQ indicator category.



Range	Suitability	Percentage (%)
[-1 , 0]	Not Suitable	44.79
(0 , 0.56]	Low	6.67
(0.56 , 0.95]	Acceptable	21.46
(0.95 , 1.05]	High	22.29
(1.05 , 1.5]	Uncertain	3.33

This study presents that during disasters there are social convergence of people and information in the cyberspace. One crucial product of the convergence is VGI. Developing from spontaneous activities in the aftermath of disasters around 2005 to a more organized volunteer-driven operation in recent Haiti earthquake, VGI is increasing accepted by government agencies, international humanitarian organizations, NGOs and grassroots organizations as an important resource for geographic information as well as an important tool for emergency communication and relief coordination. The experiences studied from the VGI implementations in disasters are summarized in next chapter. Suggestions are made to help improve effectiveness of VGI. At the same time future researches are proposed for better understandings of VGI in emergency management.

CHAPTER V

SUMMARIES AND CONCLUSIONS

5. 1. Research Summaries

Goodchild coined the phrase *Volunteered Geographic Information* (VGI) in (2007). Sui (2008) argues that VGI would not only deeply impact the production of geographic information, but would also potentially change the constitution of the whole geographic information system, which consists of hardware, software, and people. Both call geographers' attentions to the emerging citizen-driven geographic information processing. It is a new phenomenon with potential implications toward lifting many constraints on the more effective and wider application of GIS.

As a matter of fact, we do see that location information is increasingly integrated into more user generated contents (UGCs). This is due to the fact that location information is easier to get with higher accuracy nowadays. First, location information can be produced by various methods. GPS function is commonly available in many smart phones and other commercial devices. Beside GPS, geographic information can be detected by using mobile phone tower identification number, by triangulating wifi signals, by using GeoIP, or by self-reported by users. Mirror world technologies, such as Google Maps/ Google Earth, Microsoft Bing Maps, and NASA's World Winds are widely used for geographic registration of UGCs. Meanwhile, mirror worlds are treated like reality itself, which is important to support online collaboration in geographic information production. The technologies that support online collaboration are collectively called web2.0.

It is the developments in high speed Internet infrastructure, web programming methods, cellular technology and GPS technology that enable the web2.0 technologies. The availability of high speed Internet is catalyst for web2.0, because contents created by users are not only texts but also are audios, videos, and photos, whose transmission requests broad-band Internet to shorten transmission time. New web programming methods support more interactive user experience as well as lower the technical difficulties with online information creation. The developments in smart phones and other cellular technology give mobility to Internet. Therefore information searching and information sharing are more common activities in people's daily lives. Then advancements in positioning technologies link information in virtual cyberspace to physical locations on Earth's surface. All advances in technology are working to improve public's participation in online contents creation.

This research is focused on a very specific kind of UGCs that is available for one particular application, which is to engage the general public in emergency management. Because natural or manmade disasters impact many people include especially local communities. A community-level management system supported by state and federal resources are essential to cope with disasters (Canton 2007; Col 2007). Traditionally, emergency management is a command-and-control system, which relies on the power and expertise of emergency management personnel to deliver information and service to victims. The high concentration of power in a few hands of experts means failure at the command part would lead to the failure of the whole emergency management operation. An example is the failures in Hurricane Katrina that are generally cited as government policy failures. At the same time, at the community level emergency management is more about restore public welfare, health, and common ties for communities. The command-and-control approach is weak in dealing with these long-term emergency management tasks. The limitations of present emergency management approach are realized by researchers and emergency management personnel. However the attempts to incorporate public into the procedures of planning and management are rather problematic. The development of technologies and participation mechanism restricted the public from participation. First, command-and-control approach adopts a top-down approach for information communication, where public participation suggest a bottom-up mechanism for information communication, which is not well supported by the command-and-control approach. Second, the public may lack the capacity to participate meaningfully in emergency management. Part of the reason is because of the highly specialized data and tools required by emergency management, which are only affordable by governmental organizations.

Coordination, community, and information are three major requirements in an emergency management. Information as the core components enables coordination and connects communities. Updated geographic data and accurate maps are of paramount importance to a successful response to disasters. Geographic information systems are deployed in emergency management as mapping tools. Locations are underpinning for most emergency information. Hence, geospatial technologies potentially offer the common denominator to integrate information from various sources. Traditionally, geographic data are collected and maintained by governmental organizations. Because of various concerns many geographic data are not shared publicly. Meanwhile since data are collected according to the requirements of official organizations, there is a mismatch between released data and data needs of the general public. These cause the information dearth among the disaster affected population (Sutton, Palen et al. 2008). This research focuses on VGI and wiki GIS implementations in emergency management to solve the problem of information dearth among the general public.

Emergencies occur locally, where the immediate local community often responds first and copes with the situation and its consequences. This makes emergency management a community-level concern (Schafer, Ganoe et al. 2007). While much policy for emergency management is set at the state level with support from the federal government, the delivery of services begins at the local level. Thus, Lindell and Perry (1992) argue that in the development of emergency management policies, especially those associated with delivering services to the public, citizens should be involved in the process. At the same time, the balance in the relationship between the upper-level government (national and state level) and the local community should shift towards the local community (Quarantelli 1998; Murphy 2007). Many smaller local communities do not have adequate funds to facilitate local-level development of emergency systems and data collection, thus making VGI even more valuable as a virtually “free” data resource. The aggregation of VGI from different sources has the potential to create a geographic data commons (Cuff, Hansen et al. 2008), which is produced by decentralized collective actions, shared freely, and potentially useful for various geographic applications, ranging from the pursuit of science to advocacy or politics. This geographic data commons offers either a viable alternative or a complementary source to the authoritative sources of geographic data.

Many of these data commons are created voluntarily and collaboratively by the web communities. In the aftermath of Hurricane Katrina, blogs are used as portals for distributing emergency information. At the same time, the implementation of VGI in emergency management is not confined to developed countries, where technologies are more advanced. In developing countries, VGI can be even more important for carrying out emergency management operations. In Haiti earthquake, OpenStreetMap (OSM) community help create a detailed map of Haiti road networks with efforts from volunteers.

However, study finds that most volunteers are from countries with advanced Internet technologies. It is because in order to participate web2.0 communities, a user must at least have a computer and high speed Internet, which are scarcely available in many developing countries. From the 1990s to the recent years in many developed countries, the rate of high speed Internet penetration into the general public's daily life increase dramatically. At the same time the price for high speed Internet connection has dropped significantly. The constant increasing geographic coverage and decreasing cost of high speed Internet connection support the flourish of rich Internet applications.

Surveys find that younger people are more likely to use Internet for entertainment and as a platform to maintain relationships with friends and family. Generally, Internet is more deeply integrated with younger generation's daily activities. Therefore, implementations VGI should pay attention to the potential bias in the data.

Then Internet enables collaborations among users from different geographic locations. This phenomenon is commonly observed in major disasters. In 2008 Sichuan earthquake, in 2008 Hurricane Ike, in 2009 California wildfire, in 2010 Haiti earthquake, and in 2010 Chili earthquake, web communities are quickly assembled to react to the requirement of local disaster affected population. In these processes, many web2.0 applications and tools are improvised to satisfy the requirements of local communities. OSM maps are used to monitor displaced population and display information about collapse buildings and the locations of road blocks. Ushahidi platform becomes a makeshift emergency call system for local Haitians. Then a platform that connects organizations from United Nations (UN), governmental emergency management organizations, non-governmental emergency management organizations, and grassroots organizations are established within a few days after the earthquake. In Haiti earthquake VGI and wiki GIS demonstrate the capacity of collaborative volunteers in assisting emergency management based on open source tools and crowdsourced geographic data.

Traditionally geospatial data are created and published by national agencies and private corporations through top-down processes. Data quality is assured by following published standards or simply the reputation of the producer. Collectively these sorts of data would be termed authoritative data (Goodchild 2008). Recently we have witnessed the growth of neogeography (Turner 2006) that involves amateurs who have little or no training to produce map for their own purposes. This new development, on the one hand, has enabled us to observe the Earth in greater details, but, on the other hand, this new bottom-up data-collection process also poses new challenges for data quality assessment and accuracy assurance (Bishr and Kuhn 2007). While usually the quality of authoritative geospatial data is described in the “five-fold way” (might be called spatial accuracy 1.0), it is problematic to measure VGI in the same way (Goodchild 2007), and Goodchild

(2008) argued we need a shift to spatial accuracy 2.0, which emphasizes the relative data quality and accuracy of VGI to particular tasks, and lets human intelligence identify small inaccuracies in geospatial data.

Studies on the quality of OSM show that data created by different methods have different characteristics and different qualities. OSM data produced via field collection normally have the highest quality. The results of cases studies on London OSM data quality (Haklay 2008) and Houston OSM data quality present that in-situ data collection is better at catching local knowledge, such as street names and other attribute information. However, the first way requests the highest technical support and skill capacity. Then in countries, where resources of public geographic data are abundant, OSM data can be created by integrating geographic data in public domain into OSM framework. Data created by this way inherit all problems and errors from the sources, and create new problems such as duplicate points. In many developing countries, where GPS devices are not popular and public geographic data resources are scarce, OSM data are produced by using remote sensing imageries as backdrops for extracting geographic information. Traditionally, remote sensing has been the primary method used to create geospatial data. While experts use tools to help extract information of geographic features, online communities rely on leveraging the long-tail of enormous amount of volunteers. Investigations on users' contribution pattern indicate that many individual volunteers only make one or two contributions. However, by accumulating small contributions from mass individuals, the result is significant. In Haiti earthquake, road maps are created by OSM communities via manual deriving of information of geographic features. Obviously, OSM data created in this way can only preserve the geometric information. Many Haiti road features are not properly named when created in this method.

Studies on VGI and wiki GIS applications in emergency management present that these emerging tools and data are valuable for assisting public participation in emergency management carried out by governmental agencies and large NGOs. However, the link between grassroots organizations and traditional emergency management organizations is not formally established. Existing connections are temporary and non-institutionalized.

5. 2. Conclusions and Future Research

This research applies a comprehensive GIScience approach to investigate geographic distribution of creators of VGI, the quality of VGI, and its implementations in emergency management. The methodology is inductive and experimental. Multiple VGI resources and evidence of VGI applications in emergency management are collected from major disasters, which include 2005 Hurricane Katrina, 2008 Hurricane Ike, 2008 Sichuan earthquake, and recent 2010 Haiti earthquake. Methods from computer science and GIScience are integrated due to limited theory and tools in VGI, which is an emergent phenomenon.

This research concludes that VGI and wiki GIS represent new development in public participation in the production and use of geographic information. Traditionally, practices in public participation GIS are organized by the authoritative for a defined geographic project that lasts for a limited period of time. Participants receive trainings to help them grasp the necessary skills. VGI and wiki GIS are dramatically different from the practices of PPGIS. First, the whole Internet is considered as an information source.

In the application of using RSS news feeds for detecting Avian Influenza, any RSS feed can be incorporated into the system as a new data source. Then, in Wiki GIS volunteers contribute more arbitrarily. The openness of web 2.0 based Wiki GIS makes it hard to control who can access the service, and who can't. Although it is possible to provide trainings on the website, there is no guarantee that users will follow the trainings. Finally, in PPGIS volunteers act as data collectors, and data are submitted to the authoritative for quality control and data processing. In Wiki GIS either there are no officials, or the sheer volume of data makes it impossible to verify data quality manually. Information quality in Wiki GIS is maintained by peer-review.

While in traditional GIS, there are established studies for geographic information collection/ process/ distribute, system architectural design, and social economic implications, wiki GIS as a new emerge concept lacks such systematic studies. Contrast to traditional GIS, wiki GIS has several significant new characteristics. First, in traditional GIS, most hardware sets are highly specialized, and demands trained personnel to operate; in wiki GIS, such hardware sets encompass a dramatically variety of devices and instruments, such as commercial digital camera, smart phone, or portal game devices, which are used by people for all sorts of purposes. Second, in traditional GIS, software is either desktop based or web based, and for trained GIS specialists; there exists no wiki GIS implementations yet, only partial features of wiki GIS exist in many Web 2.0 applications, such as web service based (e.g. Google Maps), interactive (e.g. Geocommons), crowed-sourced (e.g. Wikimapia), and for all sorts of users. Third, in traditional GIS, the purpose of geographic information is predefined, data are collected accordingly by specialists, and information about geographic data is described in metadata; in wiki GIS, most of the time, there is a wide discrepancy between the purpose, that the information is collected for, and the objective, that the geographic information would be implemented for, for example georeferenced photos taken by tourists are used for uncovering tourist patterns (Girardin, Calabrese et al. 2008).

In emergency management, VGI and wiki GIS suggest a new approach to incorporate the general public. The potential of wiki GIS is to provide a geocollaboration platform for local emergency managers and community residents on community emergency management. Information sharing is critical to achieve situational awareness (ESRI 2008), which affects the effectiveness of emergency management. One major role of the platform is to aid information sharing among stakeholders, especially citizens. Citizens as experts of their local areas are invaluable for vulnerability assessment prior to emergency preparedness planning. The concept of citizens as sensors (Goodchild 2007) is one of the revolutions incurred by Web 2.0. Citizens can monitor the local environment (Gouveia and Fonseca 2008) by taking photos or recording videos of hazard scenes, or drawing maps showing flooded zone in their local area. These types of information are not detectable, or the costs are too high, using traditional remote sensing techniques. This is the arena where VGI has the greatest potential. They can publish their products on various Web 2.0 sites, such as Flickr, YouTube, and Google Map. Most Web 2.0 sites can provide information update functions through RSS/GeoRSS. Therefore by registering their RSS/GeoRSS on a wiki GIS, their contributions will be collectively shared among the local community. Google Map is used as background knowledge in a wiki GIS, and tools for drawing points, lines, and polygons are provided. Citizens can use those tools to annotate on Google Map to publish local emergency/hazard information, such as floodinundation, victim information, or hazard information. They can draw their own maps upon the Google Map layer, then after data quality and accuracy assessment, these citizen contributed maps could be implemented for keeping the authoritative data updated. At the same time, all user generated contents are open to the public to collectively correct errors, and to prevent vandalism. Another role of the platform is to provide local emergency/hazard early alert to local government authorities. The aggregation of VGI resources has the potential to reveal concealed geospatial patterns of VGI. By aggregating VGI from various sources, a wiki GIS can perform emergency/hazard alert by keyword detection and threshold setup. When the popup frequency of keywords increases unexpectedly in different VGI and over a threshold, alerts will be sent to local government authorities, who can pick up the information and cross-reference with their own information for decision making. We hope the development of VGI and Wiki GIS will aid the local community communication with other organizations and institutions in the process of emergency management, and enable the local community to serve as an active participant in emergency management.

While this research has surveyed VGI and wiki GIS practices in recent disasters, and presented that they are viable solution to grassroots driven emergency management. However, VGI and wiki GIS are not formalized in official emergency management practices. My future research will conduct studies on integration of grassroots and official emergency management. It will focus on geographic information communication between the two parts. This study has begun research on integration of VGI with traditional geographic information based on SDI. Next step is to develop VGI meta-data that provide crucial information that help users to determine the suitability of VGI for a task. The value of VGI and wiki GIS is gradually perceived by official emergency management agencies. They are starting to use more web2.0 tools to help distribute emergency information, and collect VGI for situation awareness purposes. Then more case studies will be conducted on practices of VGI by official agencies.

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VITA

Name: Chen Xu

Address: Department of Geography, Texas A&M University
Room 810, Eller O&M Building
College Station, Texas 77843-3147

Email Address: carlxu2008@gmail.com

Education: B.S., Automation, Sichuan University, 1999
M.S., Computer Science, Sam Houston State University, 2005