A WEB-BASED APPLICATION FOR HOME LOSS NOTIFICATION IN WILDFIRES

by

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ABSTRACT

Wildfires can threaten and subsequently impact communities, lives, and property. In the past decade, wildfires have burned over 60 million acres and damaged thousands of structures in the U.S. The condition of a home is a major concern of evacuees from fire-affected communities, and there is an increasing need to improve house-damage notification during or immediately after a wildfire, especially in cases where evacuees are displaced for an extended period of time. As a wildfire progresses, maps should be updated and disseminated in a timely manner to help people understand which areas have sustained damage. The goal of this research is to develop a web-based prototype to share timely, trustworthy home-loss information by on-scene personnel through interactive maps and dynamic graphs. Web technologies, open-source libraries, and database and cloud servers were utilized for system development. The online system supports information needs during or following a wildfire. People can be informed by system notifications regarding the damage condition of homes with up-to-date maps. The system further serves as an information hub and provides valuable home-loss datasets for postwildfire research and analysis.

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CHAPTER 1

INTRODUCTION

Wildfires can threaten and subsequently impact communities, lives, and property (Bar-Massada et al. 2013; Gibbons et al. 2012; Gill, Stephens, & Cary 2013; Syphard et al. 2012). The combination of warmer climate temperatures, drought, high winds, and an excess of fuels in forests, grasslands, and brush-lands have made fire seasons progressively worse over the past 50 years (Cohen J., 2008). In the past decade, wildfires have burned over 80 million acres of land and devastated thousands of houses and structures in the United States (U.S.). With the continuous expansion of the "wildland-urban interface" (WUI) communities under decentralized urbanization and housing development policies in the U.S., more people are moving to the WUI (Brown et al., 2005; Johnson et al., 2005; Theobald & Romme, 2007). This growing population increases housing unit density and decreases the separation distance between houses. Due to the combination of successive drought seasons, dense housing, and surrounding vegetation, WUI fires are a rapidly growing problem in the U.S., with over 46 million homes in 70,000 communities at risk (Bailey, 2013; Cohen, 2008; Gollner et al., 2015). WUI fires have caused a prominent trend of increasing structures lost in the U.S. (Stein et al., 2013). The total number of structures lost per year has grown significantly, from approximately 900 per year in the 1990s to almost 3000 per year in the 2000s (Bailey, 2013). Since 2000, over 38,000 homes have been lost to WUI fires (Gollner et al., 2015). In some cases, these were urban firestorms with losses exacerbated by the narrow separation between houses (Cohen & Stratton, 2008). For example, in the 2012 Waldo Canyon fire in Colorado, in areas where home-to-home ignition occurred, spacing between homes was only 12 feet to 20 feet (3 to 6 m) (Gollner et al., 2015; Quarles et al., 2012). Figure 1.1 illustrates the structures lost in wildfires from 1999 – 2011 in the U.S., Most structural loss occurred in the southern, mid-western, and western U.S., which have more WUI communities. However, this overwhelming structural loss continues to increase. In 2015, a total of 4,636 structures were directly destroyed by WUI fires, and most of the fires occurred in California (Badger, 2016; National Interagency Coordination Center, 2015). Among all the categories of structures lost in wildfires, primary residential structures are more commonly lost than commercial structures and outbuildings in most years (Figure 1.2). Based on our further research, we summarized wildfires where more than 50 homes were lost after 2011 in Table 1.1. An example of growing fire danger in wildfire-prone areas can be found in southern California, which has the highest property losses from fire in the U.S and endures one or more massive wildfires each decade with an average of 1000 houses destroyed per year, and from 2001 to 2010, nearly 10, 000 residential structures were destroyed by wildfires (Syphard et al., 2012).

The loss of homes in wildfires is not only a natural and built environmental problem but also a social political problem (Gill et al., 2013; Mylchreest, 2014; Paveglio et al., 2015). The condition of a home is a major concern of evacuees from fire-affected communities, and there is an increasing need to improve house-damage notification during or immediately after a wildfire, especially in cases where evacuees are displaced for an extended period of time. In order to reduce public risk and interference with firefighting efforts, evacuees are generally forbidden from entering evacuated areas to check on the condition of their homes during a wildfire. For small-scale wildfires, the evacuated zone may close for hours or days, but for some large-scale wildfires, it may close for weeks (Gill et al., 2013). For example, in the 2012 Waldo Canyon Fire, the City government received more than 8,600 registrations from evacuees requesting home-related information online after they evacuated from homes for 6 days (City of Colorado Springs, 2013). However, as the fire-affected areas are not yet safe for initial damage-assessment teams to enter, comprehensive and complete official home-loss summary can take several days or weeks for fire or emergency personnel to collect, compile, and confirm this information before imparting it to the public. In fact, most home-loss information is reported by on-scene firefighters to the local fire department gradually as the fire becomes contained without directly disclosing it to the residents. There was no source of timely home-loss notifications with up-to-date maps of neighborhood home-loss information during a fire (City of Colorado Springs, 2013). Residents often need to wait for an official home-loss announcement after a prolonged house-by-house damage assessment has been completed.

Based on often pending official sources, people experience anxiety and instinctively seek information about the status of their homes by a variety of approaches. For example, some individuals flew over the fire area prior to the institution of flight restrictions and provided photographs of the destroyed homes and devastated areas to evacuees, morning papers, and online media outlets (City of Colorado Springs, 2013). Some residents turn to informal sources, i.e., online news, websites, mass media, Volunteer Geographic Information (VGI), or social media, such as Twitter, Facebook, Google plus, Pinterest, Flickr, and blogs for home-related information. Social media plays a significant role in crisis communication, especially announcements released by officials via social media. For instance, Twitter followers of the Colorado Springs Fire Department (CSFD) and the City of Colorado Springs rose exponentially in the 2012 Waldo Canyon Fire (City of Colorado Springs, 2013). Twitter served as an online announcement board and plays an active role in information dissemination (Wang, Ye, & Tsou 2016). The United States Forest Service (USFS) public information officer (PIO) also tweeted evacuation announcements and fire-related notifications during the fire. Nevertheless, information that is collected from user-created content and not from officials comes with greater uncertainty. In a disaster, inconsistently representing information is worse than not presenting it at all, as it may confuse the public and increase stress (Petersen, 2014). Therefore, understandably, officials withhold information of destroyed homes, since information needs to be verified repeatedly to ensure its accuracy. For example, without technology supports, personnel spent 4 days for evaluating home assessment and finally reported a home-loss list 2 hours before residents were allowed to return home after being evacuated 6 days earlier (City of Colorado Springs, 2013). This kind of detailed and completed home-loss report is unusual. Normally, officials only release the total number of homes lost in a wildfire without any description about a community or a neighborhood, not to mention for each home. Home-loss information is usually reported in a text format without any associated maps, or even worse, is disseminated by oral messages via mess media or news reports, which is inconvenient for residents to look up and locate their own homes.

Since disasters have a geospatial impact, maps represent valuable communication tools for facilitating the comprehension of a disaster and assisting governmental emergency response (Petersen, 2014). As a wildfire progresses, maps should be updated synchronously to help people understand fire events and home situations as they unfold. Geospatial information and technologies are also significant in the planning, mitigation, incident response, and recovery of WUI fire hazards (Yin, 2014). However, a static or out-of-date map may not convey as much information as the public would like. Some maps are not self-explanatory to people who are unfamiliar with reading maps (Petersen, 2014). Rather than train people to engage with professional maps, it may be better for them to explore an interactive online map to find the information they need. From a user perspective, a disaster map should be simple, readable, and flexible in displaying features and layers based on user demands. Additionally, communication and information exchange are fundamental needs during a disaster, especially for a complex and unplanned wildfire disaster (Kapucu & Van Wart, 2006). As on-scene information is hard to come by in disasters, people crave interactive means for information exchange rather than just passively receiving information from the providers (McCaffrey, Velez, & Briefel 2013; Steelman et al., 2015). That is also why evacuees are prone to acquire information and knowledge about a fire from the Internet or social media spontaneously.

Upon the aforementioned issues, the objective of this research is to create a web-based home-status notification system: (1) to meet home-loss information needs of fire-affected communities by providing residents broader accessibility and timely notification of home conditions; (2) provide technical support for on-scene home-loss assessment to reduce time spent on data collections; (3) fill the communication gaps between agencies, volunteers, and personnel; and (4) study wildfire damage on homes with interactive maps and dynamic graphs. The system has been developed as an online Single Page Application (SPA), integrating with interactive dashboard, web maps, and trustworthy home-loss data sources.

It has the capability to collect, compile, process, search, and display home-loss information with interactive maps. Individuals can easily use web browser, tablets, and mobile phones to access the system online without a local desktop or application installation.

Table 1.1 Wildfire house loss in the U.S. in 2012- 2016

Duration	**Incident Name**	**Location**	**House-Loss**	**Notes**
06/04/2012 – 06/26/2012	Little Bear Fire	Ruidoso, New Mexico	254	
06/09/2012 – 06/30/2012	High Park Fire	West of Fort Collins, Colorado	259	
06/23/2012 – 07/10/2012	Waldo Canyon Fire	Springs, Colorado	346	
06/11/2013 – 06/20/2013	Black Forest Fire	Springs, Colorado	486	
08/17/2013 – 10/24/2013	Rim Fire	Sierra Nevada, California	112	11 residences, 3 commercial structures, and 98 outbuildings were destroyed
05/12/2014 – 05/14/2014	Fritch Panhandle Wildfire	Hutchinson, Texas	156	at least 89 homes destroyed
07/15/2014 – 11/18/ 2014	Chiwaukum Creek Fire	Oregon, Washington	100	
09/13/2014 – 10/31/2014	King Fire	Eldorado National Forest, Northern California	150	threatened 21, 000 structures, including 1, 600 houses
06/04/2015 – 07/22/2015	Sockeye Wildfire	Willow, Alaska	55	damaged 44 outbuildings and imperiled 337 properties
09/09/2015 – 10/1/2015	Butte Fire	Cal Fire, California	214	destroyed 135 homes and 79 other structures
06/23/2016 – 07/11/2016	Erskine Fire	Lake Isabella, Kern County, California	309	
07/22/2016 – 10/15/2016	Soberanes Fire	Soberanes Creek, Garrapata State Park, Monterey County, California	68	destroyed 57 homes, 11 outbuildings
08/16/2016 – 08/23/2016	Blue Cut Fire	San Bernardino County, California	105	destroyed 105 homes and 213 other structures
08/26/2016 – 08/13/2016	Clayton Fire	Lake County, California	300	300 destroyed and 28 damaged
11/23/2016 –12/20/2016	Gatlinburg Fire	Gatlinburg, Tennessee	2,460	Including homes and business structures

Source: compiled by authors from InciWeb website, online News, and the USDA Forest Service wildfire reports

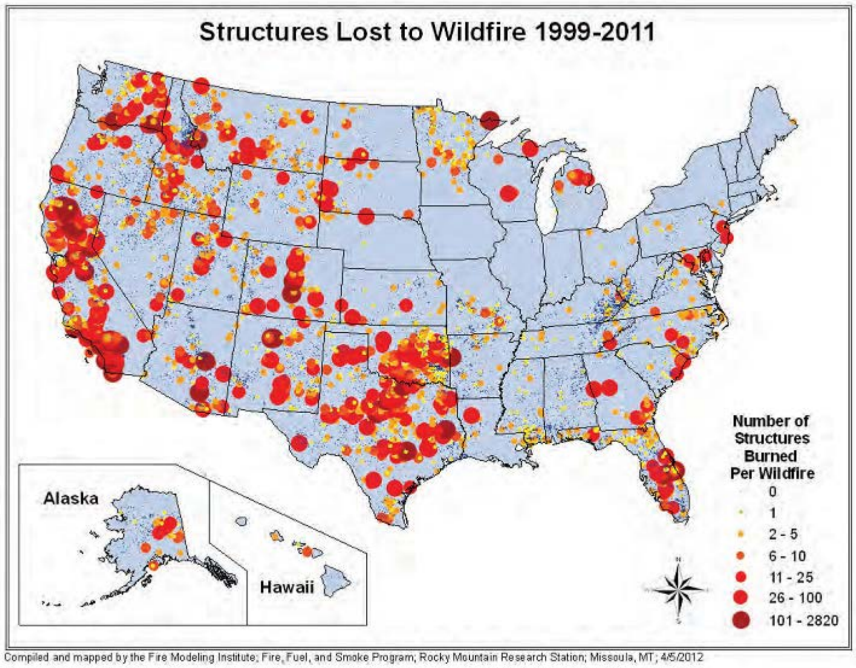


Figure 1.1 Structures lost to wildfire from 1999 to 2011 in the U.S. Reprinted from "Wildfire, wildlands, and people: understanding and preparing for wildfire in the wildland-urban interface-a Forests on the Edge report" by Stein et al., 2013, *USDA Forest Service. Gen. Tech. Rep. RMRS-GTR-299, Rocky Mountain Research Station, Fort Collins, CO*. Retrieved from https://www.fs.fed.us/openspace/fote/reports/GTR-299.pdf. Copyright USDA Forest Service. Reprinted with permission.

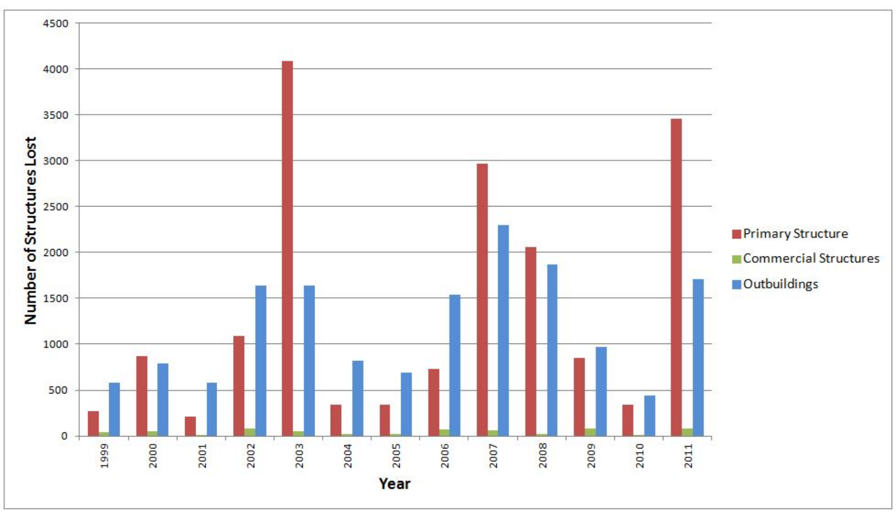


Figure 1.2 Wildfire Structure loss data by category from 1999 – 2011 Reprinted from "More than 2,600 structures lost per year due to wildfire. National Fire Protection Association." by Haynes, 2012, National Fire Protection Association (NFPA), Retrieved from https://community.nfpa.org/community/fire-break/blog/2012/10/01/more-than-2600-structures-lost-per-year-due-to-wildfire. Copyright by Hylton Haynes. Reprinted with permission.

CHAPTER 2

LITERATURE REVIEW

2.1 WUI Communities and Home-loss Notification in Wildfires

WUI development is widespread across the conterminous U.S., covers about 10% of the land area, and contains 33% of the housing units (Radeloff et al., 2005). There are 220 million acres of WUI overlaid with 46 million single-family homes, several hundred thousand business structures, and an estimated population of over 120 million people (Bailey, 2013). As the WUI creates an environment for fire to move readily from grasslands, shrub lands, and forests into neighborhoods, WUI community expansion has increased the number of structures, homes, and people that are threatened by wildfire in those wildfire-prone areas (Bar-Massada et al., 2013; Martinuzzi et al., 2015; Radeloff et al., 2005b). There are two categories of WUI: interface WUI and intermix WUI. Houses in the interface WUI are grouped together and adjacent to dense natural vegetation areas, whereas houses in the intermix WUI are mingled or interspersed with vegetation (Martinuzzi et al., 2010; Stein et al., 2013). Although wildfires pose a likelihood of economic damage to many houses in the WUI, the wildfire risk across the WUI communities varies from areas to areas in terms of vegetation type, climate and seasonal weather patterns, and housing densities (Stein et al., 2013). In those wildfire-prone WUI communities, the housing pattern and density can have a great impact on the spread and intensity of the fire once it has started, and the level of economic damage in wildfires (Blonski, Miller, & Rice 2010; Cohen, 2000; Stein et al., 2013; Syphard et al., 2012).

Houses are the focal point of human activity in WUI communities. They are readily threatened by wildfires and have a high risk of igniting (Cohen, 2000). Therefore, housing growth in the wildfire-prone WUI areas challenges fire management and firefighting. Over the past 70 years, housing growth in the WUI area has grown faster than population because of an increasing number of smaller households and seasonal homes (Stewart et al., 2007). In the U.S., about 59% of seasonal houses are within the WUI (Martinuzzi et al., 2010). However, the large proportions of seasonal homes results in a denser population in the WUI during the summer season, while the social complexity of the WUI community challenges the ability of emergency managers to control and manage wildfires (especially for human-caused wildfires), further raising wildland fuel treatment and wildfire suppression costs (Hammer et al., 2009; Jackes et al., 2007; Paveglio et al., 2009). For example, many seasonal residents did not respond positively in fuel management and refuse to regularly clear brush or gutters at their vacation home, as they will not spend much time there (Winter, Vogt, & McCaffrey, 2006). It is difficult to coordinate wildfire prevention programs and activities for seasonal residents and their houses as they are often absent (Winter, Vogt, & Fried, 2002). This demonstrates the magnitude and the complexity of the WUI fire protection problem facing the U.S. (Bailey, 2013) Therefore, WUI fire growth increases the necessity of notifying residents of timely home-loss information when a wildfire occurs.

Notifying people regarding home-loss information efficiently and getting evacuees back into their neighborhoods in a timely fashion are two issues that need improvement

(Brenkert-Smith, McCaffrey, & Stidham, 2013). So far, official home-loss information is still deficient and inefficient during or immediately after wildfires. In the U.S., there are three departments involved in wildfire management: local fire departments, federal fire personnel, and law enforcement. The local fire departments take responsibility for structure protection, the federal fire personnel are in charge of wildfire suppression, while law enforcement (in cooperation with the National Guard) manages evacuations and roadblocks (McCaffrey, Velez, & Briefel, 2013). Generally, local fire departments are responsible for notifying individuals about house loss or damage after wildfires. This process includes three steps. First, assessors from the county emergency office tour the evacuated neighborhoods to identify burned structures and hand over the resulting house-loss list to the sheriff's office. Homeowners are notified individually about their house status soon after the list is confirmed by officials. Nevertheless, this notification process usually takes at least 1 week, which is too long for some residents and evacuees to wait, and as such, they often express frustration with the existing inaccuracy and delayed notification on structure damage and loss (McCaffrey, Velez, & Briefel, 2013).

Residents and evacuees wish to confirm which homes have burned, and when they can return to their neighborhood. They continuously seek information from different sources to check on the status of their homes. So far, there are two informal ways for residents to learn the status of their home: sneaking back into evacuated areas themselves, or contacting individuals who have access to the roadblock zone to check on the house status (McCaffrey, Velez, & Briefel, 2013). The only formal way for individuals to acquire house loss information is speaking with the most reliable local contacts. One official interviewee from McCaffrey's survey (2013) said, "I think it was very frustrating for people to go a week or

5 days not knowing whether their house survived, not knowing what they need to do to plan if their house had been destroyed.” Without trustworthy information about the status of homes, residents and evacuees are unable to take further actions after wildfires. Therefore, it is significant and necessary for government officials to provide house-loss information in a timely and trustworthy manner in order to satisfy people’s information needs in wildfires.

2.2 Trustworthy and Timely Information Needs in Wildfires

Trustworthy and timely information is essential and significant for effective wildfire response, control, and management. The information communication loop includes a set of relationships among senders and receivers (Fessenden-Raden et al. 1987; Renn, 1991). Understanding the feedback from receivers is critical for information agencies because they should make sure the provided information is meaningful to those who are seeking it (Quarantelli, 1988). While many studies have been performed on establishing effective risk and crisis communication in wildfires (Reynolds & Seeger, 2005; Steelman & McCaffrey, 2013; Witte & Allen, 2000), the perspective of receivers about whether these sources or information are useful and trustworthy is often ignored (Steelman et al., 2015). Recently, social scientists studied information needs before, in, and following wildfires. Steelman, McCaffrey, Velez, and Briefel (2015) explored what information is used, useful, and trustworthy in wildfires by doing surveys based on five recent wildfires. They found that people prefer to trust and use official sources that come from governments (e.g., Local Fire Departments and the Incident Management Team), rather than unofficial information derived from mass media or social media, such as television, news, Twitter, Facebook, or

Blogs. Petersen (2014) compared two wildfire maps of the 2007 Southern California Fire: one was created by San Diego County's Emergency Operations Center, and the other was created by local media and academic institutes on Google My Map. Interestingly, she found that these two maps indicated different fire perimeters of the same wildfire. She further discovered that the unofficial Google wildfire map, which was created by the ad-hoc group, stated that it was not responsible for wildfire response and liability as the county map did. The objectives of the unofficial wildfire map were to provide substantial, relevant, and up-to-date pictures or information as much as possible to individuals but with no claims to information accuracy and completeness.

Admittedly, both official and unofficial sources are important in disaster communication (Fitzpatrick & Mileti, 1994). Residents acquire fire information wherever it comes from during wildfires, i.e., local authorities, mass media, Google My Maps, or Twitter (Goodchild & Glennon, 2010). Taylor et al. (2007) insists that the public uses multiple sources, including both official and unofficial information, to gain a big picture of a wildfire disaster. However, as individuals can share information more easily via Internet in the changing communication environment, residents begin to turn to alternative unofficial sources, i.e., social media and the VGI, rather than the inefficient and limited official sources, especially for urban residents who are more likely to use blogs, Facebook, and Twitter to acquire wildfire information than rural residents (McCaffrey, Velez, & Briefel, 2013; Shklovski et al., 2008; Steelman et al., 2015). Goodchild and Glennon (2010) studied crowdsourcing geographic information for a series of Santa Barbara wildfires between 2007 and 2009. They found that crowdsourced data, which come from dense observers, are ideal for filling the need for near-real-time information needs in wildfires.

Social media data have also been increasingly used for disaster assistance, emergency management, and situational awareness (Bruns & Liang, 2012; Fohringer et al., 2015; Huang & Cervone, 2016; Olteanu, Vieweg, & Castillo, 2015; Sutton, Palen, & Shklovski, 2008; Vieweg et al., 2010; Wang, Ye, & Tsou, 2016). It also has been widely utilized in wildfire contexts. Goodchild and Glennon (2010) studied crowdsourced data and VGI use in wildfire responses in Santa Barbara from 2007 to 2009. They found that Flickr served as an alternative to official sources for the 7-day fire with user-uploaded images of the Gap Wildfire in July, 2008. In the Tea Fire (November, 2008), VGI immediately became an efficient information source with various data forms, such as text reports, micro-blogs, photographs, and video. Again, in the Jesusita Fire (May, 2009), several ad-hoc groups established online volunteer maps by synthesizing the official sources and VGI. Slavkovikj et al. (2014) gave a review of systems and methods that enable the use of social media in wildfire disaster management. Wang, Ye, and Tsou (2016) studied wildfire-related Twitter activities to gain insights into revealing and characterizing wildfire situational awareness in space and time with social media data. They found that individuals were interested in communicating wildfire-related situational updates using Tweets, e.g., wildfire damage, wildfire response, and appreciation to firefighters.

Undoubtedly, social media is much more accessible and efficient for disseminating near-real-time information during a wildfire compared to official information. However, the likelihood of transmitting misinformation persists among social media networks. It is necessary to carefully filter user-created information and guarantee that only accurate information reaches the public. Individuals must have confidence not just in the contents of the information, but also in its source. If the information source is officials, people are more likely to accept and trust it. McCallum et al. (1991) declared that individuals tend to rely on filtered information rather than to analyze original risk information in a disaster. Accordingly, people will filter their information first based on its source in order to decide whether trust it or not. Mileti et al. (2006) found out that receivers prefer to believe and respond to those warning messages that come from official agencies. Comparing the federal sources with the local sources, several studies found that people see information from the local officials (i.e., local fire protection or local emergency management) as trustworthy information sources in wildfires (Fessenden-Raden et al., 1987; Jungermann et al., 1996; Wray et al., 2006). Social media is still deemed untrustworthy unless the information comes from individuals with access to official personnel (e.g. members of local government agencies or the fire department) (Shklovski et al., 2008; Steelman & McCaffrey, 2013). Consistent with Starbird and Palen's findings (2010) that users prefer to retweet authoritative emergency-related information from local media and traditional service organizations, Wang, Ye, and Tsou (2016) also found out that wildfire situational announcements from authoritative sources are dominant in retweet networks because of their accuracy and objectiveness.

2.3 Web-based Technologies and Applications Used in Wildfire Context

Apart from trustworthiness, efficiency, and visualization are another two important characteristics of crisis information sources needed in a wildfire. A web-based crisis information system can freely coordinate on-scene efforts and resources to collect near-real-time data, connect off-scene individuals in an emergency, and release crisis information with interactive web maps in wildfires. Web-based technologies have been widely utilized in wildfire response and management because of their efficiency of information dissemination and interactive visualization capabilities. During a disaster, interactive sources are characterized as reducing information uncertainty. Transmission of crisis information is also flexible with web-based communication tools. Citizen participation in providing user-created information in crises has been active through social media recently (Hong, 2014). They have started using Twitter, Facebook, Flickrs, and blogs as a near-real-time communication tool during wildfire emergencies. These web-based social media applications are not only capable for individual's daily communication, but also provide efficient information from user-generated content that can benefit crisis communication (Brengarth & Mujkic, 2015). Brengarth and Mujkic (2015) examined how web applications and social media were used in wildfire to transmit emergency information for leveraging nonprofit responses. They found out that web technologies serve as a bridge between on-site relief workers, populations in danger, and individuals who were trying to help.

Advanced web-based wildfire applications, integrated with web technologies and standards and geospatial technologies – Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), Spatial Data Infrastructure (SDI), and Open Geospatial Consortium (OGC) web services – facilitate sharing rich spatial information online and geo-visualization maps (Aye et al., 2015). Web-based GIS applications have played a significant role in areas including, but not limited to, disaster management, emergency response, decision making, and information communication in various natural hazards. Although an increasing number of applications have been developed in a wildfire context, most of them focus on wildfire preparedness and response, such as wildfire prediction, monitoring, control, management, and decision making (Ambrosia, Sullivan, & Buechel, 2011; Baranovskiy & Zharikova, 2014; Davies et al., 2009; Harzallah et al., 2008; Kalabokidis et al., 2013; Kearns et al., 2008; Roberto Barbosa et al., 2010; Yin et al., 2012). Some wildfire studies have turned to wildfire evacuation, rescue, data analysis, and visualization with social media and VGI data (De Longueville, Smith, & Luraschi, 2009; Kent & Capello, 2013; Liu & Palen, 2010; Pultar et al., 2009; Slavkovikj et al., 2014; Tsou & Leitner, 2013; Wang, Ye, & Tsou, 2016). However, no study has been done on home-loss notification to meet information needs in fire-affected communities in or after wildfires.

CHAPTER 3

SYSTEM DEVELOPMENT

3.1 System Introduction

This pilot system was implemented as a responsive SPA with a web-based Graphical User Interface (GUI). The SPA technology increases the fluid user experience by reducing response time to user actions without constant page reloads (Figure 3.1). In addition to its integration with a web-based GUI, the online home-loss notification system gives a user the feeling of desktop software, with updates to a portion of the page without refreshing the whole page. The system is different from traditional web applications in that it communicates with the server by requesting a new HTML page every time the SPAs load a single HTML page after the initial request, then dynamically updates portions of that page as the user interacts with the application (Wasson, 2013). Interaction with the server happens via AJAX (Asynchronous JavaScript and XML) requests with a response in the JSON format without HTML markup (see Figure 3.1, SPA Lifecycle). This data interaction approach, which sends data as JSON instead of a new HTML page, separates the presentation (HTML markup) and application logic (AJAX requests and JSON responses), as well as isolating the client side and server operations (Fielding, 2008; Wasson, 2013; Web Camps Team, 2015). All user interaction occurs on the client side in JavaScript and CSS, and only interacts with the server via HTTP calls. The server side, on the other hand, acts purely as a web service layer after the initial page load.

The system is a two-tier system with a client side layer and a server side layer. The client-server communication of the home-status notification system was developed with the RESTful web service. The client side communicates with the server by making RESTful API calls to the server side (Figure 3.2). Then the REST web service uses HTTP requests (call to URLs) to GET, PUT, POST, and DELETE data with a response in JSON format (Field, 2008; Fielding, 2000). There are two advantages of using the RESTful APIs. On one hand, it isolates frontend and backend workflows and development. System update or maintenance can be finished on the server side without involving the client side, whereas data visualization can be done on the client side without server side involvement. Furthermore, the client can also cache a request response (JSON data) for later use without equivalent requests to the server database, which avoids interaction latency and improves system performance. As JSON is a light-weight format in the web-based environment, it improves data communication efficiency and makes the system mobile-friendly.

3.2 System Framework and Technologies

Figure 3.3 illustrates the framework design of the two-tier home-status notification system. The server side of the system includes RESTful APIs, along with the data administration engine and database. The RESTful APIs are primarily developed with Node.js and Express web framework providing nonblocking data inputs and outputs (I/O) for the system. Express is a framework for building web applications on top of Node.js, which simplifies the server creation process. While Node.js allows using JavaScript as the server side language, which utilizes the client side and server side development using the same language. The system database is developed with the NoSQL database MongoDB and saved to the Mongo DB cloud database service mLab. Rather than using pure Mongo scripts to modify databases and the Mongo Driver to process MongoDB data objects, the data administration engine was developed to assist data processing, filtering, translating, and management on the server side. The engine was mainly implemented with Mongoose – a Node.js library to provide MongoDB object mapping. It translates data from databases to the JSON format using JavaScript within Node.js interface. Multiple data updates or multiple databases maintenance can be done by applying the MongoDB management tool (GUI client) Robomongo. This GUI tool helps connect to the mLab cloud database service platform with GUI, which is easier for system administrators to maintain the system databases.

Considering the high performance of data read/write, data query, and database scalability for future extension, the system utilizes MongoDB as its backend database engine. MongoDB is one of the most popular open-source databases for Big Data with advantages of providing high-performance queries, full-text search, and support of spatial query from large datasets (Tsou et al., 2015; Yang et al., 2016). In addition, MongoDB uses dynamic schemas and stores data as a set of key-value pairs that can vary in structure, which is more scalable than static schemas used by relational databases. For example, new data records can be created without first defining the structure, such as the fields or the types of their values. Administrators can easily change the structure of data records by adding or deleting fields. Also, as a high-performance database for data read/write, MongoDB works efficiently and perfectly with Node.js and Express frameworks rather than relational databases. Database management and administration are in the charge of system administrators on the backend server side. When creating, updating, and maintaining large or multiple datasets, system administrators can use the MongoDB administration tool Robomongo without involving the client side. For small data updates, such as updating information for a single home, changes can be accomplished via the system interface. For example, once a wildfire happens, system administrators can create a new home database without any damage information using Robomongo on the server side. After the database is created, on-scene personnel can immediately access the system to modify any home status information using the system interface. Home status information can be easily changed from “visible damage” to “complete” damage by on-scene personnel as the fire burns. After information was confirmed on the server side, end-side users can receive a notification regarding that home. For oral and lengthy home-related messages, Public Information Officers (PIOs) will help system administrators filter, verify, and interpret spatial attributes and visual relationships before updating the database.

The client side of the system contains an interactive dashboard, visualization, and analytics engine for rendering home data (Figure 3.3). We used a map canvas and a hidden sidebar menu to present a dashboard-like interface, which provides users the experience of using a desktop-software in the web-based environment. Users can easily access built-in functionalities with dashboard components without leaving the main page. Such an interactive system interface is built around Bootstrap, AngularJS frontend frameworks with HTML, CSS, and JavaScript extensions. Mapbox GL JavaScript library serves as a mapping engine to render interactive maps for the system. Compared with a traditional online mapping engine with 2D flat maps, the Mapbox GL JavaScript Library is able to embed interactive, customizable vector maps into the system. It is built around vector tiles using the Web Graphics Library (WebGL) – an open-source JavaScript API for rendering 3D and 2D graphics within the web browser without using any plug-ins and Leaflet APIs – an open-source JavaScript library for mobile-friendly interactive maps (Tavares, 2012). As a client side library, data rendering is able to be completed in a browser without involving the server side. The library also allows for dynamic styling, freeform interactivity, and vector 3D surroundings as in a video game. The user can zoom in or out of maps smoothly and rotate maps in all directions.

The visualization and analytics engine is responsible for displaying the home-loss situation with interactive, dynamic data visualization. As continuous updates of home status information occur, analysis graphs and data rendering are renewed correspondingly in the browser upon receiving changes from the server databases. We used the D3.js open-source JavaScript library for implementing dynamic, interactive data visualization in web browsers. The library combines powerful visualization components and a data-driven approach to Document Object Model (DOM) manipulation, which allows great control over the final visual with extraordinary flexibility and efficiency, and supports large datasets and dynamic behaviors for interaction and animation in modern browsers (Bostock, Ogievetsky, & Heer 2011). Upon those updated analysis graphs and visualizations, the user can get an overview of the home-loss situation at a glance. Moreover, the user can explore information details by interacting with the graph components. To summarize, the aforementioned key technology, tools and their functionalities are listed in Table 3.1.

3.3. System Components and Functionalities

The major functionalities and innovations of the home-status notification system include the following:

1. Visualizing up-to-date home status information with interactive maps and analysis graphs for the calculation of the home-loss situation in a fire-affected community;
2. Searching for damage information for a specific home, and filtering homes to display damage levels;
3. Pushing real-time notifications of home-loss updates to the client side;
4. Sharing home-loss information as links or embedded maps to social media and other websites;
5. Reporting incorrectness of data errors and privacy issues;
6. Editing, updating, and verifying home information on the server side without involving the client side.

Table 3.2 lists the built-in features/functions of the system. Some functions can be used by both users and system administrators, while some special functions can only be used by system administrators. The following sections will further introduce how to employ these built-in features/functions, how to interact with the dashboard, and how to use the system.

3.3.1 System Dashboard

When users first access the system, the interface is shown as in Figure 3.4. Users can use the system easily to search, track, and characterize home condition information. At the top of the map canvas, a search panel with geo-location functionality is used for finding and locating a specified home. Users can type in an address, and it will transport the user to that home on the map. On the left of the map canvas, the sidebar menu is a collapsible dashboard for the system that contains 10 components. Users can interact with different components on the dashboard without leaving the main page. Figure 3.5 presents the layout of the unfolded sidebar menu when hovering over it. To begin with, users can select a wildfire database to see its home-loss situation using the Wildfires component (Figure 3.6). Since a community may undergo more than one wildfire, the damage condition of each home may be different in different wildfires. After users choose a specific wildfire database, the related home-loss data will be rendered on maps. To display homes in different damage categories, users can apply the Layers component by filtering layers upon different damage levels. Only selected layers will be presented on maps. For example, users can browse only homes that had been damaged in a fire on maps by selecting layers of completed damage and visible damage from the layer panel (Figure 3.7). The other home layers will be filtered from maps. There are five different categories of the description of home status, i.e., no visible damage, visible damage, complete damage, uncertain damage, and no information. The description of each category of homes is shown in the case study section (see Chapter 4). Users can easily identify each category of homes based on its symbol. Also, users can easily switch base-map styles using the Settings panel (shown as Figure 3.8) to view home data in different map styles. The system provides six types of base maps, i.e., Basic map, Streets map, Bright map, Light map, Dark map, and Satellite map.

As a home-status notification system, users can be informed immediately when a home was reported damaged by on-scene personnel in a house-by-house search and damage assessment. The red badge on the sidebar menu represents notifications for new updates of homes and the number shows how many homes have been updated in the system database.

For example, the red badge with a number 5 (see Figure 3.5) means information for five homes had been updated on the server side. Users can click to view these homes on a map. Notifications can not only be viewed via the system, they can also be shared as a link or embedded in maps on other websites, social media platforms, or by emails using the Share component (Figure 3.9). If users find any error in the updated home status information, maps, or notifications, they can leave comments/feedback via the Support component (Figure 3.10), as well as further support regarding issues such as report home information, questions towards unclear description, or problems of using the system. The system uses Google Forms to collect all comments and feedback from users and sends them to the administrator for reference. Considering privacy concerns from homeowners, the system also sets up a Privacy Report panel for users to report privacy concerns (Figure 3.11). It also uses Google Forms to record information and messages from users first, then administrators will further contact each user with emails. For example, a user can leave messages with their identification and emails for their privacy reports (i.e., please remove a house from the public database), then system administrators will contact the user for a solution and feedback.

3.3.2 System Visualization and Analytics Engine

The system provides several ways to present home damage information with maps. The first one is simply by hovering over a home on the map. A pop-up shows above the home with its status information (Figure 3.12 a). For more information about a home, users can employ the Status Information panel to see the damage condition, data source, created time, and last update time (Figure 3.12 b). Rather than rendering hundreds of thousands of homes on the base-map, the system adopts a point clustering method from Mapbox GL JS to display home data on the map in a simple and efficient way. Figure 3.12 c is the clustering of homes at a specific zoom level. Circles with larger number represents more points underneath. When zooming into the map, these circles are replaced by more circles with smaller numbers. For example, a circle with a number 123 on it means there are 123 homes underneath. As one zooms into the map, it will be replaced by other smaller circles with smaller numbers. There are three levels of clusters. Each circle level has a different background color. The pink circle layer represents clusters that have greater than or equal to 150 homes. The yellow circle layer represents clusters that have greater than or equal to 120 homes but less than 150 homes. The blue circle layer represents clusters that have less than 120 homes. As the map continues zooming in, eventually all the circles will be replaced by dots showing each house on the map.

The point clustering method, also called hierarchical greedy clustering, unlike more sophisticated clustering algorithms, can be fast and clear enough to handle millions of home points on an interactive map in the browser (Agafonkin, 2016). It groups points into clusters for a specific zoom and represents each cluster using a circle with a number on it. The spatial index allows a user to instantly query clusters for any map view. A map with a cluster visualization of damaged homes provides users an overall understanding of the spatial pattern, distribution, trend, and situation of home-loss in fire-affected communities. The number showed on each cluster represents the number of homes belonging to that cluster, in other words, the number of homes has been lost in a specific area. Clusters of homes are different for every zoom level of the map with a unique spatial index. Such a home-cluster-map may also benefit wildfire response and rescue teams in fire-affected areas.

In addition to maps, graphs, and photos, such as home-loss accounting, photos of the broader fire-affected area can also provide home-loss situational awareness for users. The Graphs and Statistics panel provides a unique way to understand the overall situation of homes burned by a fire using analysis graphs. The graphs are dynamic and interactive. They change according to updates in databases. For example, when a fire first begins, there was no information for home loss, thus, the analysis graphs are empty. As the fire progresses, the analysis graphs would be charted automatically as more and more home-status information had been recorded and updated to the home database. Users can interact with analysis graphs to explore a summary of homes that had been lost to the fire, and the percentage of homes in different damage categories. Besides, the gallery panel presents photo slides for comparison of before and after views regarding a fire-affected neighborhood. The before views of a community can be remote sensing images, or aerial photos from the governmental departments, while the after views of a fire-affected community can be photos including but not limited to remote sensing images or photos taken by on-scene personnel or offered by other third-party organizations. In the case study section, we can further see how the aforementioned interactive and dynamic data visualizations assist in understanding overall wildfire damage to homes.

Table 3.1 Key technology and tools used for home-loss notification system

Technology/Tools		Functionality
Client Side	Bootstrap	Use for interface, dashboard, modal design and layouts
	Mapbox JavaScript Library	Use for data clustering, layers rendering
	Mapbox GL Javascript Library	User for vector 3D base-map rendering
	D3.js	User for visualizing home-loss analysis graphs
Server Side	Node.js	Backend framework
	Express	Frontend framework
	MongoDB	Use for storing large home databases
	Mongoose	Use for processing data transfer between client side and server side

Table 3.2 Built-in features and functions of the home-loss notification system

Feature/Function	User
Search, visualize home-loss information on maps	√ ○
View home-loss situation calculation & analysis in graphs	√ ○
Filter display layers, switch base-map styles	√ ○
Report errors & privacy issues	○
Share maps	√ ○
Update home-status data, manage databases, push home-loss notifications	√

Note: √ represents feature/function that can be only used by administrators, ○ represents feature/function that can be used by both administrators and users

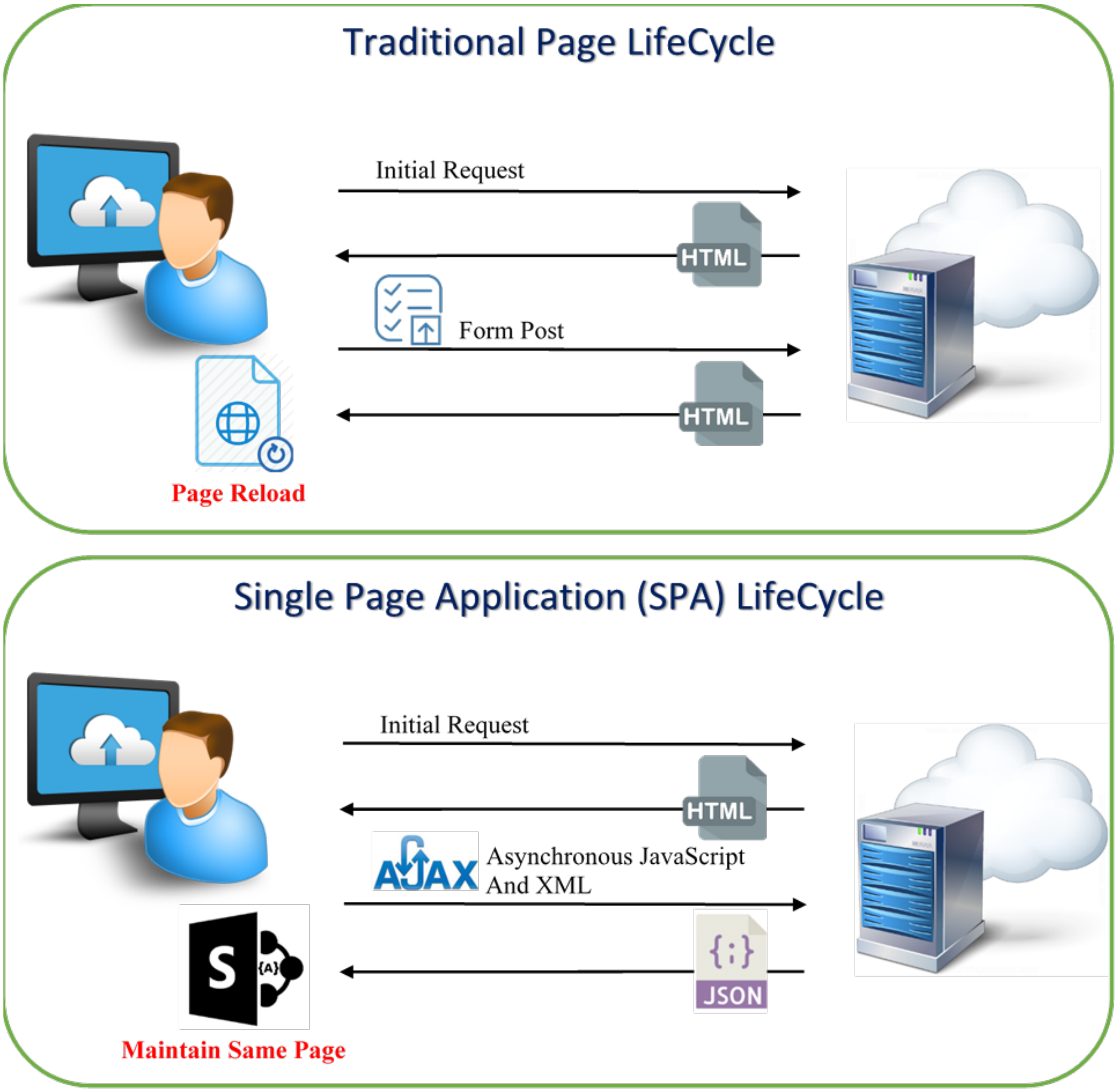


Figure 3.1 Traditional Page Lifecycle vs. SPA Lifecycle

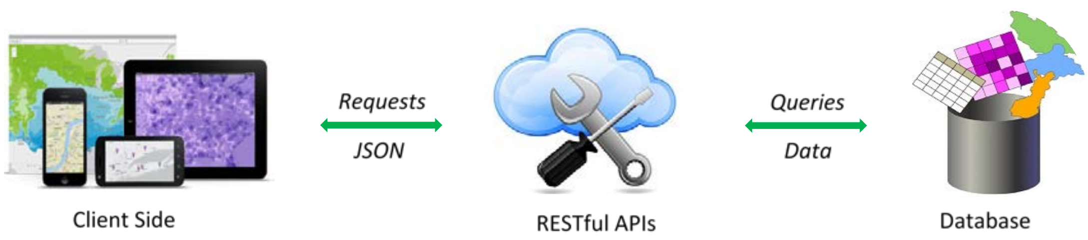


Figure 3.2 The communication workflow of home-status notification system

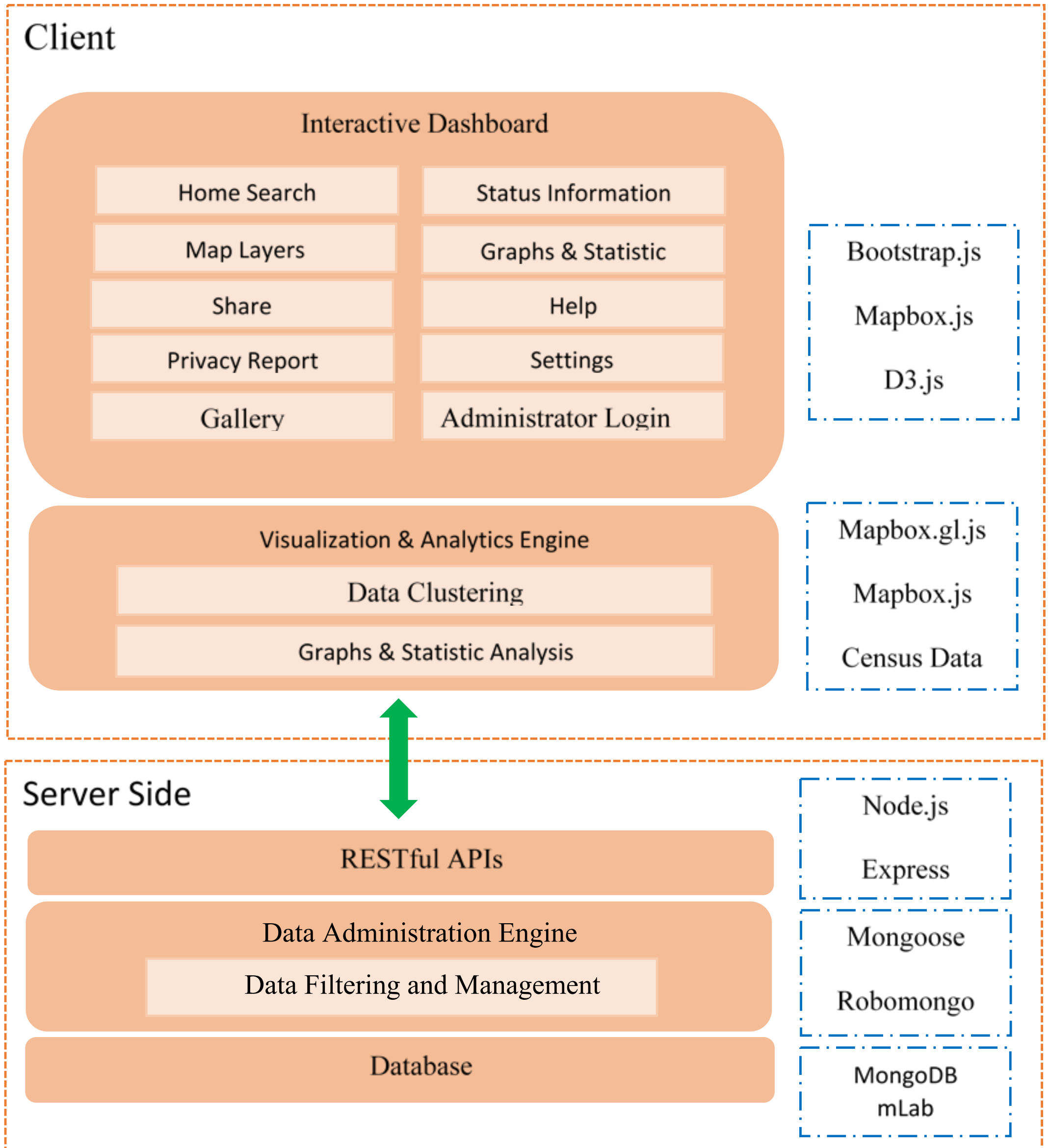


Figure 3.3 The client side and server side technological frameworks of the system

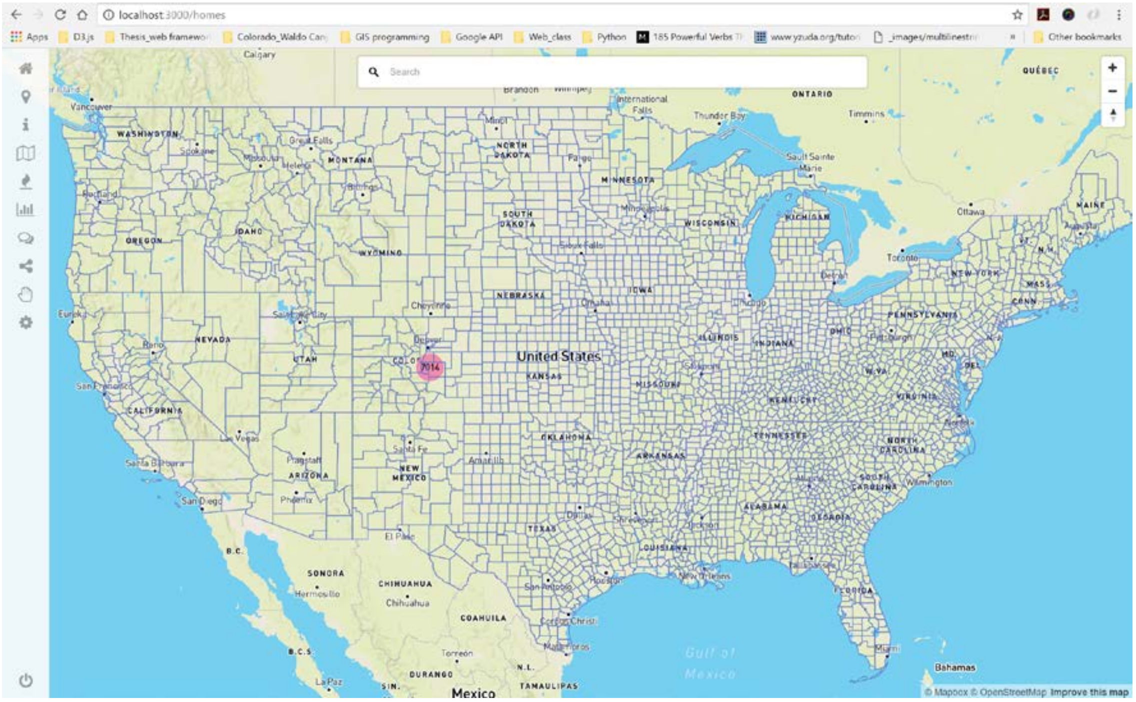


Figure 3.4 The user interface design of home-status-notification system

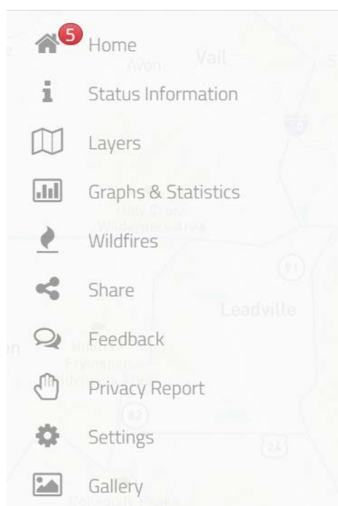


Figure 3.5 The sidebar menu design with new home-loss notifications

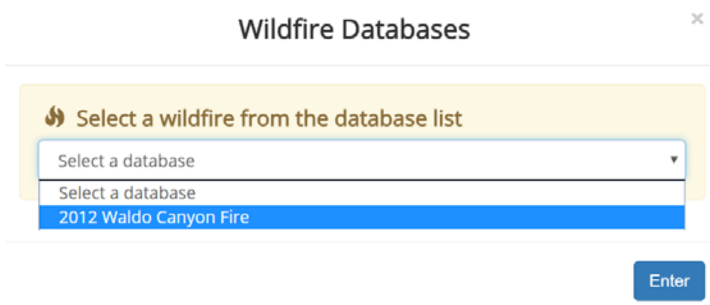


Figure 3.6 The design of wildfire database panel

Figure 3.7 The Layers panel design for filtering home layers upon damage levels

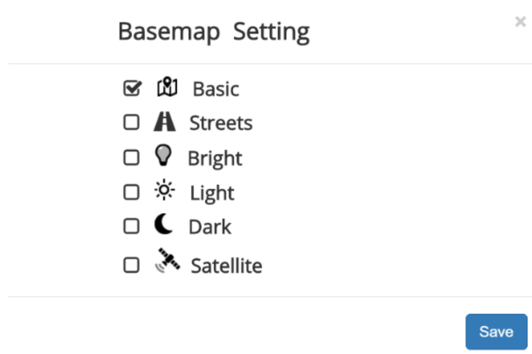


Figure 3.8 The Settings panel design for switching base-map

Figure 3.9 The design of Share panel

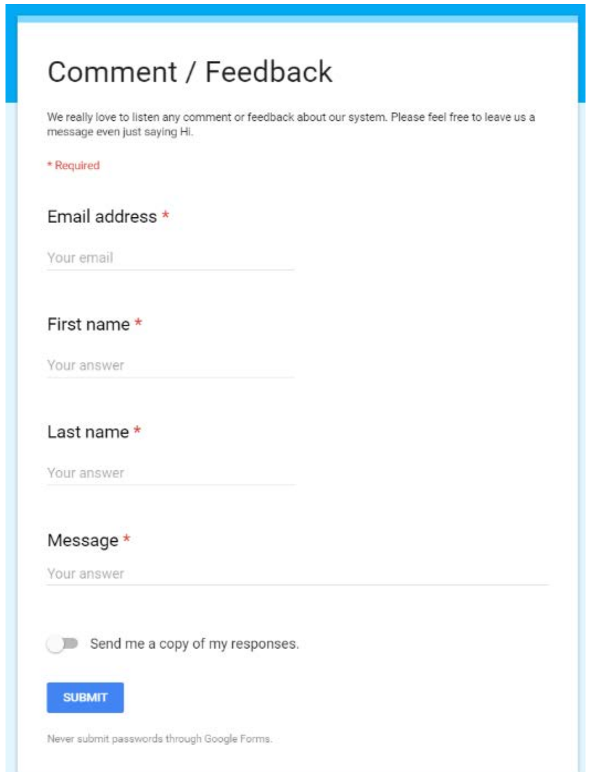


Figure 3.10 The design of Supports panel

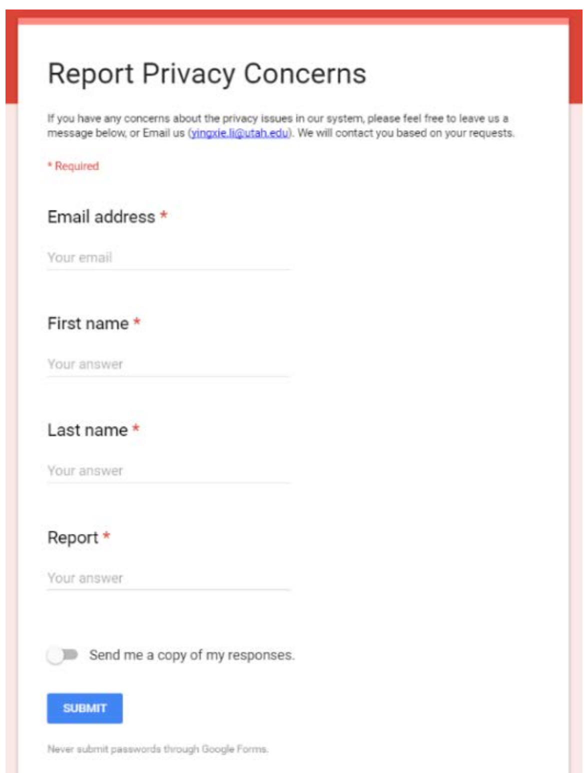
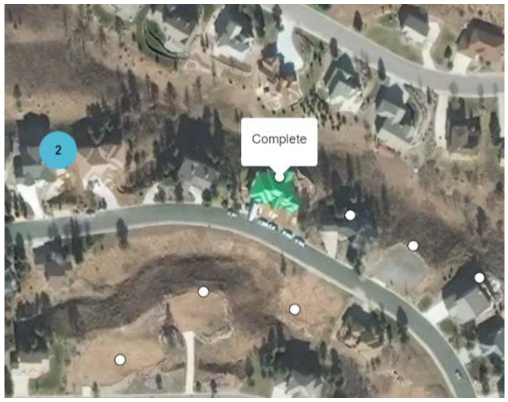
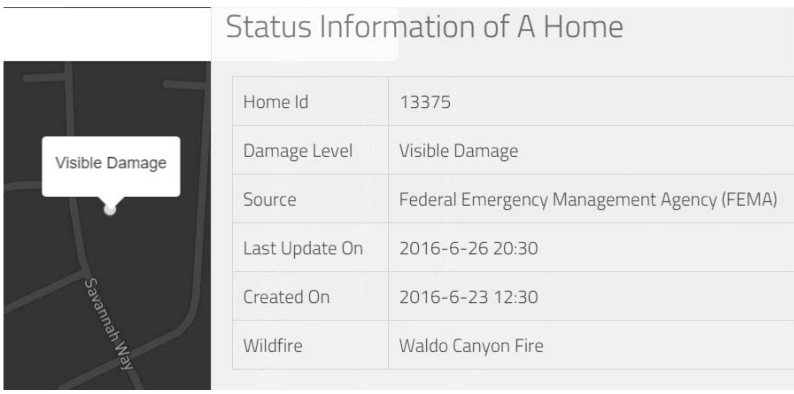


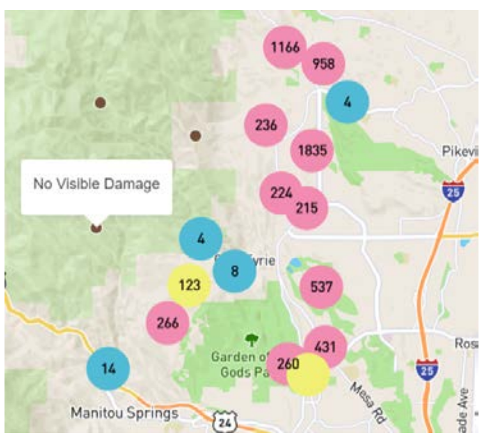
Figure 3.11 The design of Privacy Report panel



a. A pop-up tag for damage condition of one home



b. A side panel for detailed condition information of one home



c. A cluster map of damaged homes at a specific zoom level (pink, yellow, green circle represent different levels of clusters)

Figure 3.12 Different approaches for presenting home damage condition

CHAPTER 4

CASE STUDY OF THE HOME-LOSS NOTIFICATION SYSTEM

In order to evaluate the utility of the system dashboard and the built-in functions, this section presents a case study to highlight the practical uses of the home-status notification system for visualizing the home-loss situation in a wildfire. The 2012 Waldo Canyon Fire was used as an example, which stands as the most destructive wildfire in Colorado state history that destroyed 347 homes (18% of the 11,308 buildings in the fire-affected area) in 2 days (City of Colorado Springs, 2013). It began on June 23, 2012 and was fully contained on July 10, 2012, while most of the homes were burned on June 26th and 27th, 2012. To be specific, the fire burned 18,247 aces (74 km^2) over 18 days, impacted 30 to 35 streets, and caused the evacuation of 32,000 residents (City of Colorado Springs, 2013). The home-loss dataset we used was provided by the Federal Emergency Management Agency (FEMA) with spatial information and the damage condition of every home in the fire-affected area. This dataset includes 7014 homes in total, 349 homes completely damaged, 37 homes with visible damage, and 6628 homes with no visible damage.

For our case study, we set up a home database with five features, i.e., OBEJCTID, Damage, Source, Wildfire, createdOn, and lastUpdate. Table 4.1 introduces what these features represent. Considering that in a real fire, a home may have different conditions at different times, and conflicting information or no information may also occur regarding a home, we assumethat homes would have information, such as “No Visible Damage,” “Visible Damage,” “Complete Damage,” “Uncertain Damage,” and “No Information.” Each category is a layer with a unique symbol showing on maps (Table 4.2). “Uncertain Damage” are those homes that have conflicting information regarding their damage situation. These homes should be reevaluated and confirmed by on-scene personnel again. Homes with a “No Information” tag are those homes with unsure damage situations. These homes should be marked down by the administrator and sent to the damage assessment team for a further investigation.

In our simulation of using the system to notify residents of the condition of their homes in a fire, we referred to the Waldo Canyon Wildfire day-by-day timeline report compiled by Cotter, Fellers, and McMillin (2012) and Final After Action Report (City of Colorado Springs, 2013) released by Colorado Springs. They provide a narrative overview of the fire behavior and fire progression, which gives a snapshot for key aspects of the fire and home damage condition. The fire actually started on June 22, 2012, but it was not visible until June 23, 2012 at 12:30 pm (Waldo Canyon Fire Update, 2012). We assumed that the home database was able to launch soon after the fire was reported to the local fire department, and was ready to use on the last day of the fire to record the condition of homes. The condition of each home in the database was initialized to “No Information.” Every time when a home was reported to be damaged, its situation will be changed from “No Information” to “Complete Damage” or “Visible Damage.” If a home was saved by firefighters and without any damage by the fire, its situation would be changed to “No Visible Damage.” If a home has conflicting information regarding its damage condition, its situation would be changed to “Uncertain Damage” first, then wait for further confirmation from on-scene personnel. If a home did not have any information regarding its condition, its situation value would still be "No Information" and wait for further updates from on-scene personnel. There was no home lost or damaged between June 23 to June 25, 2012 in the Waldo Canyon Fire. However, on June 26, 2012, due to the hot, dry weather (reaching an all-time high of 101 degrees) and massive winds (up to 65 mph), a firestorm pushed the fire into the western edge of the City of Colorado Springs (Waldo Canyon Fire Update, 2012). Based on the timeline report, between 5 to 6 p.m., structures were initially reported as burned. Multiple structures, at least 20, were on fire between 6 to 7 p.m. based on cell phone service reports. From 7 to 8 p.m., firefighters reported structure-to-structure ignitions. After 8 p.m., 65 mph winds drove flames over containment lines, and more buildings started burning to the ground. Homes kept burning down until 10 p.m. From 10 p.m. until midnight, not only residential homes, but also commercial structures, were threatened by the firestorm. Finally, after 6 a.m. on June 27th, the wildfire damage to homes had been contained based on Colorado Springs Utilities reports that no more facilities had burned.

According to the aforementioned timeline of the home-loss situation, we simulated an approximate number of homes that were reported to be destroyed or damaged at different time intervals. We assumed that the home dataset was ready and launched on June 23th 12:30, 2012. The damage condition of each home was initialized as "No Information." Administrators would gradually update the condition of a home at different times following the timeline report of the fire. For example, the conditions of 20 homes were changed from "No Information" to "Complete Damage" at 2012-06-26 18:30 as the cell phone service reported (Cotter, Fellers, & McMillin, 2012). Users can easily view the home condition in the fire-affected area from the client side using the system. The system not only provides users the last update time of a home's condition, but also provides a way for users to see how long it has been since the last update to a home's record was made (Figure 4.1). Users can check a home's condition by simply hovering over a home point, then a pop-up would show the information of a home, including the last update time and how long since the last update was made. Users can also see the overall home-damage situation of the fire-affected community with clustering maps (Figure 4.2). They can provide users where homes were clustered and distributed. If users only wonder about homes that had been lost in a fire, they can further filter layers of damaged homes by selecting "visible-damage-home" and "complete-damage-home" layers and unselecting other layers via the Layer panel (Figure 4.3 and 4.4). The analysis of the home-loss situation among fire-affected areas would be automatically calculated and illustrated with interactive graphs in the Graphs & Statistics panel (Figure 4.5). These graphs can dynamically change as new home-loss data come into the database without manual re-creation. For example, the graphs were empty when the fire first began as there was no home loss in the fire. As more and more information of home-status was updated in the database regarding the conditions of homes, the graphs would be filled. Users can interact with those analysis graphs to discover more detail about the home-loss situation. For example, in Figure 4.5, a pop-up of graphic details showed that 8.7% of homes were "Uncertain Damage" in the fire-affected community until now. In addition, the gallery panel presents photos of some fire-affected communities before and after views, which also helps user to get awareness of how their communities looks after the fire. Figure 4.6 is the gallery panel for showing users some photos or images regarding the fire-affected areas. Users can use this panel to get an awareness of what their community looks like when they cannot enter the fire-affected communities.

To summarize, the case study demonstrates the feasibility of using the system to notify off-scene individuals about up-to-date home-loss information with interactive maps in a fire. We tested all the built-in functions and the system dashboard with sample home-loss data of the 2012 Waldo Canyon Fire and provided screen shoots of the results. We assumed that the home dataset would be able to launch for the system soon after the fire started. Status information of each home can be updated by on-scene personnel and administrators gradually as the fire proceed. Users can be notified immediately on the client side regarding new updates of the condition of a home in the database, as well as how long since the last record was made. A home-cluster map can provide an overall understanding of the spatial distribution of homes in the fire-affected area, and users can further explore only damage homes by filtering different home layers on the map. The calculation of the ongoing home-loss situation was illustrated with interactive graphs. These graphs will be automatically re-created when new data come into the system database without interrupting users. Also, the gallery panel provides a slide of photos regarding the before and after views of the fire-affected area, which can give users an awareness of how the fire-affected communities look soon after the fire.

Table 4.1 Data features in the sample home database

Feature Name	Description
OBEJECTID	A unique ID number for each home point, created automatically when add a new home
Damage	The home condition or damage situation, categorized in five types
Source	The source origin, which organization/department provides the information of home status
Wildfire	Which fire (the name of a fire)
createdOn	When the home information first be created, including date and time
lastUpdate	When the home information last be updated, including date and time

Table 4.2 Different categories of layers based on the damage situation of a home

Category	Symbol	Description
No Visible Damage		a home without any visible damage
Visible Damage		a home with some visible damage
Complete Damage		a home that burned to the ground
Uncertain Damage		unsure about the exact damage condition of a home and wait for updates or conformation
No Information		still have no information about the status of a home, wait for updates

Figure 4.1 Homes with different condition information
(Assumed that "today" is the date 06/28/2012)

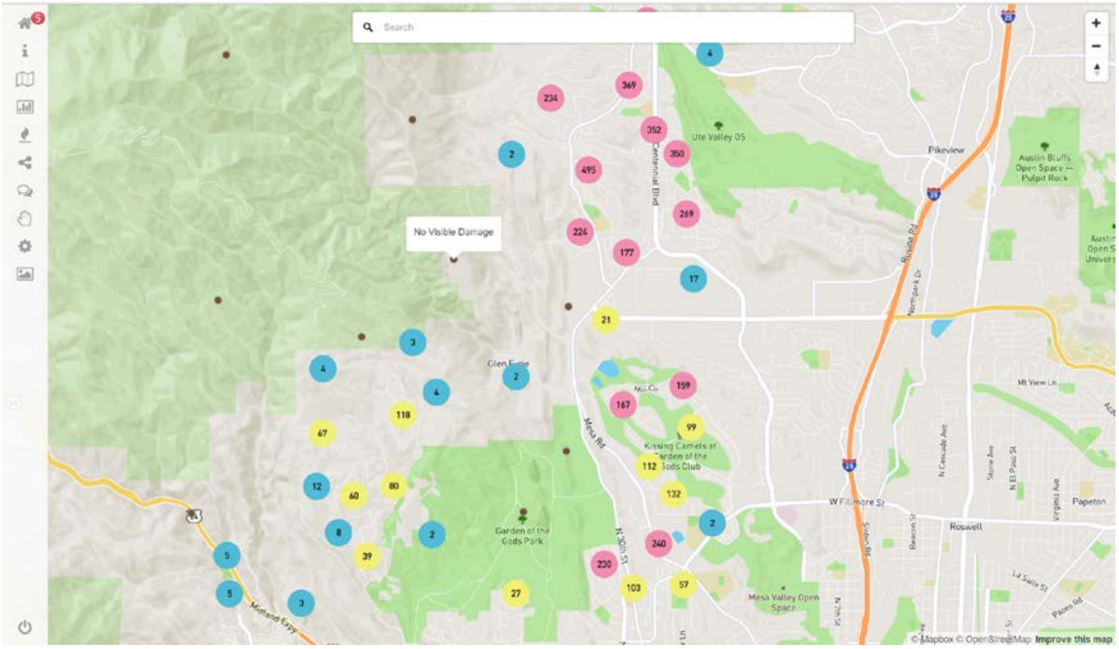


Figure 4.2 The clustering map of fire-affected homes for the Waldo Canyon Fire

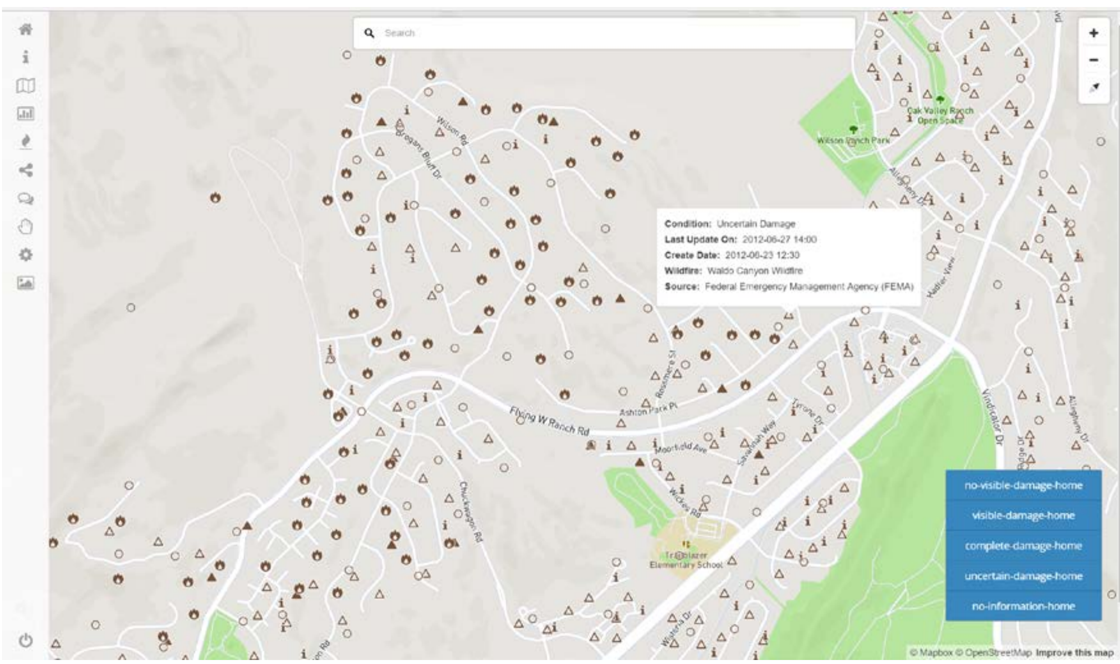


Figure 4.3 A map with all home layers
(comparing with Figure 4.4)

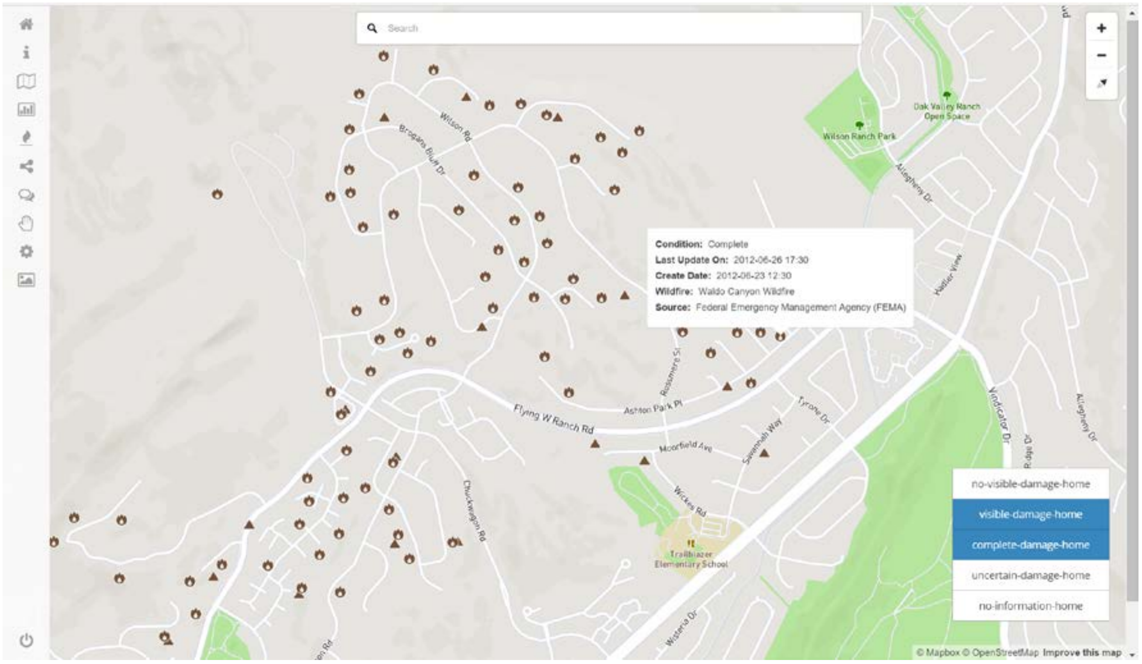


Figure 4.4 A map with only damaged home layers
(comparing with Figure 4.3)

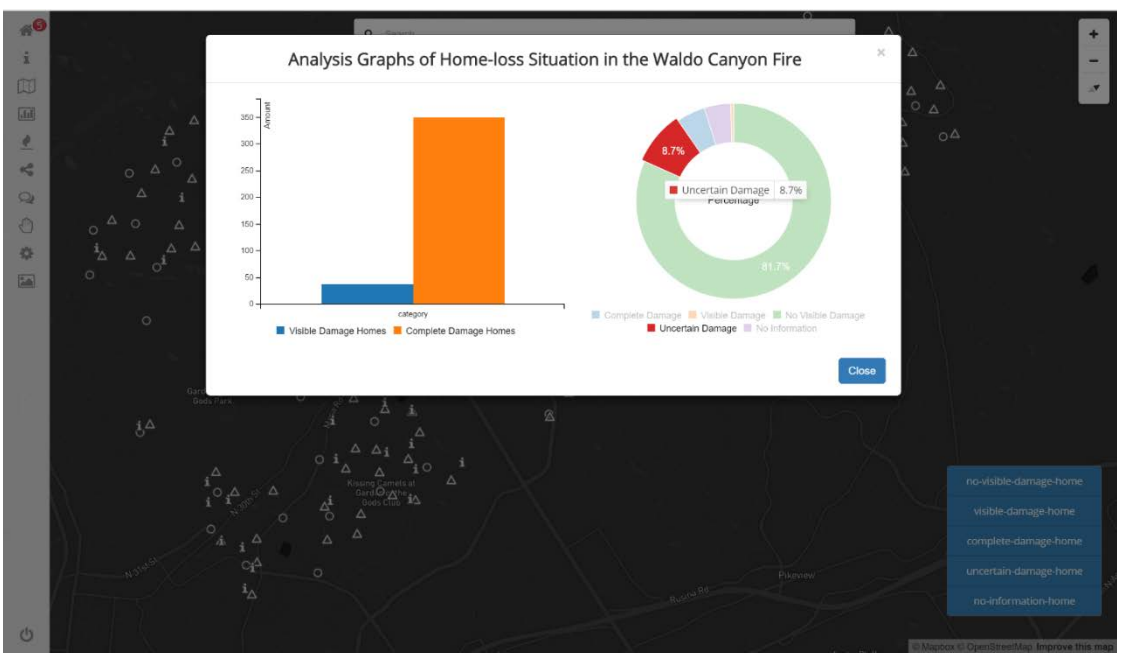


Figure 4.5 The Graphs & Statistics panel of home-loss situation
for the Waldo Canyon Fire
(base-map is set to the Dark one from the setting panel)

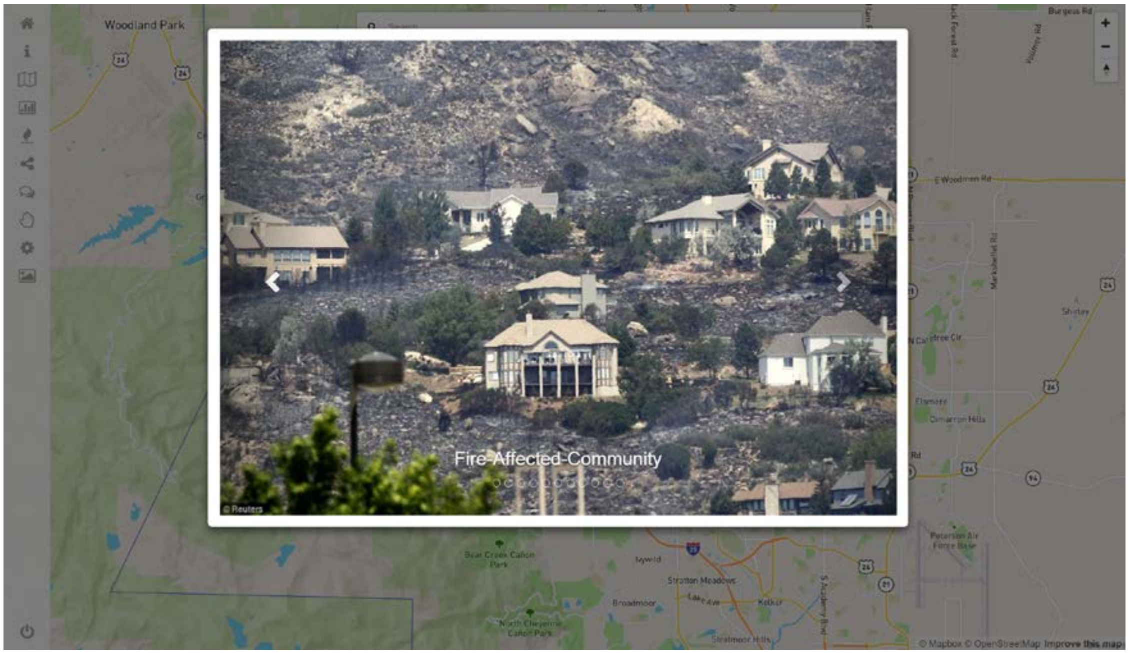


Figure 4.6 The Gallery panel of the system regarding the Waldo Canyon Fire

CHAPTER 5

DISCUSSION AND CONCLUSION

Disaster response requires timely, actionable information (Dailey & Starbird, 2016). For the first few weeks of a crisis, there is a pressing and dynamic information need from disaster-affected communities (Dailey & Starbird, 2016). A crisis map is the most frequently requested in-depth information resource by the public. Therefore, an updated map of damaged homes in fire-affected areas is desired from evacuees after a wildfire evacuation. Collecting and releasing information of general home conditions using a web-based system increases the efficiency, accessibility, and interactivity of the home-loss notification in a wildfire. Firstly, the web-based home-loss-notification system aids in performing a house-by-house damage assessment to meet information needs in fire-affected communities. Assessment-teams or other personnel (police, PIOs, public communication staff) can use the system for a home damage assessment once a fire has been contained or to record damaged home information reported by fire-fighters during a wildfire. For on-scene assessment, personnel can use the system with mobile devices to capture home conditions interactively on maps instead of using written notes during an on-scene assessment. Secondly, rather than the traditional way of disseminating home-loss information with tabular tables several days or weeks after a fire containment, the online system presented in this thesis can help notify off-scene residents regarding home-loss information with interactive maps in hours. Normally, without technical infrastructure support, home-loss notifications are disseminated by personnel, volunteers, or scouts to residents, which takes substantial time and effort. However, with the assistance of the web-based system, once a home has been confirmed as damaged and updated to the cloud service database, users can be informed immediately by receiving a notification on the client side. This provides a continuous update process for releasing up-to-date home-loss notifications to off-scene users. Sometimes information comes in forms that are difficult to map, i.e., voice messages, images without descriptions, texts without locations, and phone calls (Petersen, 2014). In this case, PIOs need to withhold the home condition information until it can be verified. They can then translate this information with spatial attributes before updating to the system database. Moreover, as the system presents home-loss information with interactive maps and analysis graphs, users can search, locate, and acquire valid home-status data using the system instead of seeking home-loss information from less reliable sources. Also, the maps and analysis graphs can be renewed automatically without interrupting users. Lastly, the system database is valuable for postwildfire research, analysis, and community education. Researchers can study the pattern, distribution, and situation of structures lost in a wildfire with interactive maps and dynamic graphs, as well as the spatial arrangement and location of burned houses, and evaluate recovery and adaption of the rebuilt houses long after a wildfire. These types of studies are significant for urban planning, landscape design of future development, target fire prevention, and community education for fire adaption in the future (Alexandre et al., 2015; Alexandre et al., 2016; Botts et al., 2015; Syphard et al., 2012). Furthermore, past inappropriate land-use decisions and landscape planning have placed many houses in areas and locations with a high vulnerability to wildfires (Gibbons et al., 2012; Mockrin et al., 2016; Pincetl et al., 2008; Syphard et al., 2012). The home-loss datasets can assist researchers in postwildfire study and analysis, such as assessing wildfire damage on houses, discovering spatial arrangement and location effects on home-loss, guiding house rebuilding, community recovery, and local migration after a wildfire.

There are two major challenges looking ahead to implementing the home-status notification system: (1) who should gather, control, and maintain valid home condition data for the system, and (2) how should location privacy be managed regarding concerns from homeowners that do not want their home information available to the public. First, unlike extracting scattered, informal home-related information from social media, online news, mass media, or even personal connections, data we used for the system should be reliable and valid. Admittedly, third-party services and information resources are woven into emergency response and can be widely useful and disseminated. However, as many of these online services are not designed for use in crises, the reliance on them raises a set of concerns, such as if they can reach the most affected portions of a community in a disaster, and whether we know the demographic characteristics of information providers and potential biases under their observations (Dailey & Starbird, 2016). Dailey and Starbird (2016) suggested employing technical infrastructures like a community-based information hub through a free website (which relies on a hosting service) to disseminate disaster-related information, while using third-party services and resources as a core tool for communicating information with disaster-affected communities. Such an online information hub can fill information gaps in a disaster and eliminate biases of disseminated information. Rather than being treated as an informal information hub only used for wildfire home situational awareness with unofficial data sources, we see the system as an official place for official home-loss information display. The best way to ensure reliable data is using official data sources, either ground data collected by on-scene personnel during a wildfire, or data compiled by local fire departments. However, different fire-affected communities addressed home-loss information needs in somewhat different ways. State-level policies, and county and city regulations have an effect on the home-loss notification process, which raises an issue of who has the responsibility for home-loss compilation and notification using the system. Based on this research, local government organizations, fire departments, county governments, emergency management centers, or the U.S. Forest Service have released home-loss information in different jurisdictions and fire-affected communities. For small wildfires, local fire departments, working with local governments and police departments, address home-loss investigations themselves. In large wildfires (Type 1 incidents), the U.S. Forest Service may get involved. For example, in the 2012 Waldo Canyon Fire, the CSFD was the lead agency for Fire Incident Response, with multiple aids from numerous agencies and volunteers. CSFD personnel and PIOs took responsibility of imparting evacuees with accurate information after home-loss accounts, with assistances from agencies such as the County Assessor's Office, City GIS Center, and CSPD (Final After Action Report, 2013). Therefore, we assume that local fire departments will mostly likely be in charge of home-loss notification and update for the system with data source information for user reference.

Second, the location privacy concerns from some homeowners may prevent the release of information about their home condition after a wildfire. Location privacy concerns arise as a result of the development of a location-awareness environment (Worboys & Duckham, 2004). Unlike many other types of personal information, identity may be inferred from location information and precise location can uniquely identify people more than names or even genetic profiles (Duckham & Kulik, 2006). Individuals become increasingly vulnerable to identification as the accessing of their location information widens (Seidl, Jankowski, & Tsou, 2016). Not surprisingly, not every homeowner is willing to disclose their home condition with the public online, and some homeowners may not feel comfortable if their location information is made public. In our research, we expect that the disclosure of the home-loss data in a disaster is influenced by the emergency situation rather than the public's concern of privacy. For example, Sevier County officials (Sevier County, 2016, December) released an interactive map online to show how structures fared during the Gatlinburg wildfire (the fire destroyed or damaged more than 1,700 buildings). Kar and Ghose (2014) found out that people are motivated to share accurate location information that is relevant to the disaster. Li and Goodchild (2013) found out that people may be less worried about the disclosure of their geopersonal information online, such as location of their presence, home, and workplace, comparing with credit card, bank accounts, and individual health information. There are two reasons: (1) users sometimes have to give out their personal information to take advantage of the convenience and efficiency of information and communication technologies; e.g., people give out their home, workplace, and real-time locations when using Google Maps to search and find directions between two places; (2) home location may no longer be a secret in the era of big data as many people are willing to share their location information when using location-based services; e.g., millions of people contributed location information to predict real-time traffic for route suggestions (Li & Goodchild, 2013). Moreover, people can easily locate and identify their home from the fine resolution of Google Street View photos and the satellite images that Google Map provides at any time and any place.

However, there still will be some people who do not like to share their geopersonel information. For example, older generations (35+ years) are more concerned about their own privacy and protecting personal information than younger age groups (Kar & Ghose, 2014). Given privacy issues, laws and regulations are enforced by government agencies to ensure privacy protection before sensitive geo-data are released to the public (Li & Goodchild, 2013). For example, generally, local governments only make the overall number of homes lost in a street or a fire-affected community public without further details regarding to a home's status after a fire. In some states, the accessibility of the home-loss information is only limit to homeowners who lost their homes in the fire without involving the whole community. For instance, on the public meeting held for imparting affected residents home-loss information in the 2012 Waldo Canyon Wildfire, residents were required to provide identification to attend, and the media was asked to respect resident privacy and only interviewed anyone after the meeting (Final After Action Report, 2013). Additionally, the City of Colorado Springs announced its commitment to attempt personal contact for those who were unable to attend the community meeting, prior to releasing the address list of damaged or destroyed homes to the public (Final After Action Report, 2013). In this regard, the current design of the home-status notification system has taken several approaches to protect the geoprivacy of homeowners. For example, (1) it preserves the disclosure of the original data - the home address and spatial location information have been removed and hidden from both frontend display and backend databases, which also prevents privacy disclosures on the server side, and only presents home damage condition for users on the client side; (2) it minimizes the exposure of precise locations of a home on the map by limiting the zooming resolution; (3) it provides a report and feedback procedure where homeowners can request to hide/remove the status information of their home from the map with identifications if they have further privacy concerns.

Also, some limitations of the key libraries/software we used are another challenge for the system implementation. First, although MongoDB works perfectly with Node.js and Express frameworks on the backend, MongoDB stores data as a document with various data schema in a collection (database), which creates a lot of duplicate data and it is not friendly for relational data. It is convenient as the duplicate data were already presented wherever we need; however, they are dangerous when one needs to update/modify since it means walking through all different places that data appear in to change. This is very error-prone, and may lead to inconsistent data and errors, especially for deletions. For the system, we tried to store data in different collections by categorizing homes in different types and separate each home in a documentation, which can be easier for us to update/compile data in the future.

Second, since the map datasets of Mapbox are based on open-source OpenStreetMap, it has limitations on performing data-heavy and very detailed map datasets comparing with other map renderers (e.g., GoogleMap, ESRI online map). For example, when we rendered GeoJSON data (home points) in our case study, we cannot find the correspondent geometry of homes on the base-map unless switching to the satellite style (Mapbox map datasets), while the GoogleMap and ESRI provide more detailed map datasets for their map tiles with which we can see the correspondent geometry of homes on the map. However, as we developed the system only based on open-source libraries/software, we decide to choose

Mapbox, which is an open-source client side map renderer for web platforms with rich built-in visualization features. When interacting with a map rendered by Mapbox GL library, it provides a fluent experience the same as panning across a large, continuous image.

Third, D3 is a great library for dynamic data visualization in modern web browsers, e.g., Chrome, Firefox, Safari, and Opera; however, it does not support older browsers, e.g., IE6, 7, and 8 (even 9 is a bit sketchy). Besides, D3 does not generate predetermined visualizations, which is inconvenient for developers for checking the results. The result charts only showed when running codes in browsers. D3 has a time-ineffective learning curve for beginners as dealing with DOM nodes is complicated and sometimes frustrating. In our case study, we used C3.js – a D3-based reusable chart library for generating D3-based charts by wrapping the reusable D3 code to construct some basic analysis charts. By using the library, charts can be updated even after they have been rendered. In future research, there are several things that can be done for improving the system. Firstly, more case studies of different wildfire scenarios should be applied to test the usability and enrich the system database with reliable home-loss data, and the system should have its unique website and URL for free sharing of home-loss information as an online information hub in a wildfire. An open-access system will extend the accessibility of home-loss situations and meet information needs not only from fire-affected communities but also from nation-wide individuals. Secondly, instead of leaving messages and waiting for feedback from system administrators, the system can embed the Live Chat feature for answering user inquiries regarding privacy issues, data inaccuracy, and system instructions online, which can improve communication interactivity between users and administrators. For further geoprivacy protections, we can limit the access to detailed home information to homeowners only, or using geographic masking techniques to preserve spatial patterns of the original dataset. Besides, the system should have correspondent documentation, manual, or youtube videos to train and tutor administrators and personnel how to prepare and use the system, especially for individuals who administer or control the system in a fire. Because disasters and emergencies are unpredictable, administrator and personnel training and preparation of the system should be done before a fire actually comes. Therefore, the system should provide a tutorial with sample data for training purposes. While for the user tutorial, the system can embed a quick, simple instruction step by step for new users who first visit the system. Lastly but not the least, the system prototype also needs to be evaluated by professionals and researchers from fields such as disaster response, emergency management, data visualization, and web mapping. They can provide expert reviews regarding the user interface design, features design, built-in functionalities, and professional suggestions for future improvements. For example, although the system is developed for notifying home-loss information in a wildfire, it could also be used for any home-loss scenario in a large-scale disaster, such as flood, tornado, hurricane, and volcano. Thus, the system can extend its features and functions to satisfy the need of home-loss notification in various disasters.

To summarize, the web-based home-status notification system serves as an online information hub, addresses timely, trustworthy home-loss information, and meets home-loss information needs from fire-affected communities. With state-of-art web-based technologies and open-source libraries, the system is designed as a SPA with interactive dashboards, webGL maps, and dynamic analysis graphs. It gives users a desktop-like experience while interacting with the system in a network environment. The 2012 Waldo Canyon Wildfire case study demonstrates the usability of the system, interactive dashboards, functionalities, and dynamic home-loss analysis. With the capability of addressing home condition information with up-to-date maps, the system is not limited to discovering patterns and insights of wildfire damage on homes, and can be extended to postwildfire study domains such as spatial arrangement of home rebuilding, community recovery and adaptation, urban planning, and landscape design for fire-adapted communities.

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