

# THEORETICAL FRAMEWORK FOR A MOBILE EMERGENCY DECISION SUPPORT AND ROUTING APPLICATION

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## ABSTRACT:

The Mobile Emergency Decision Support and Routing Application (MEDSRA) is a location-based service that can help individuals, families and organizations make informed decisions when threatened by hazardous events such as wildfires, earthquakes, tornadoes, hurricanes, industrial accidents, and terrorist actions. The application first locates the user on a map, then draws from a multitude of data sources to display the location of hazards, road closures, emergency shelters and evacuation zones, as well as the locations of other people within a user-defined disaster support network (DSN). One important feature is the ability to communicate instantly via text and pictures with other application users, thus incorporating both official data sources and volunteered geographic information (VGI) into the decision making process. This application also features an advanced routing algorithm that can suggest the best routes using GIS data and real-time traffic conditions. A demonstration scenario of the MEDSRA is developed based on the May 2009 Jesusita Fire in Santa Barbara county.

## 1. INTRODUCTION

On May 5, 2009 the Jesusita Fire broke out in the foothills above Santa Barbara, California. Although the region had faced three wildfires in the previous three years, this fire constituted the largest threat to the city as a whole, necessitating the evacuation of nearly 30,000 residents. By most accounts, the threat posed by this hazard was handled well: fire fighting resources were allocated efficiently, citizen evacuations went smoothly, and loss of property and life was minimized. According to emergency managers and citizens affected by this fire, up-to-date emergency information was often difficult to obtain and accuracy was questionable. This was due in part to the availability of large amounts of user generated content available over the Internet, which often differed from information available through traditional sources such as radio and television.

Sharing accurate and timely geospatial information is crucial to successful management of hazardous events (National Research Council, 2007). Effective emergency information interchange is important within a first responder or emergency management group, within a personal circle of family, friends, and co-workers, and between these groups as well. Traditional modes of communicating emergency information such as radio and television are being replaced by the Internet and mobile devices, thus we should consider how best to harness the power of these technologies to prevent a hazard from becoming a disaster. One conundrum faced by the emergency management community is how to deal with the flood of volunteered geographic information (VGI) that is available and may conflict with information from official sources. This paper presents the theoretical framework for a location-based service that can be used during emergency situations to help make decisions using geospatial information from both official and unofficial sources. The application we describe is designed for a consumer mobile device, but similar systems could be

designed for first responders, the Red Cross, or other groups involved in emergency management.

## 2. BACKGROUND

### 2.1 VGI and Decision Support

Using volunteered geographic information (VGI) to improve emergency management has been proposed, but implementation has thus far been limited by the lack of tools necessary to collect, process, and synthesize data (Goodchild, 2007). The Mobile Emergency Decision Support and Routing Application (MEDSRA) can help fill this gap by allowing users to share text, pictures, and video within a defined disaster support network (DSN). This approach allows users to take advantage of the risk-management benefits provided by a flexible, robust communication network (Comfort, 2005), and make decisions using both the VGI from DSN members and geoinformation from official sources. Other Decision Support Systems have been designed for emergency management, allowing users to simulate and assess evacuation plans (de Silva and Eglese, 2000; Hobeika et al., 1994), develop flood mitigation strategies (Levy et al., 2007; Shim et al., 2002) and estimate casualties and sheltering needs due to an earthquake (Aleskerov et al., 2005). The widespread adoption of mobile communication technologies has led to the development of mobile decision support systems (Yeu et al., 2001; San Pedro et al., 2004; Padmanabhan et al., 2006), most notably to assist emergency personnel with triage. The near-instantaneous communication and collaboration made possible through mobile devices presents a new and exciting range of possibilities for decision support applications (Shim et al., 2002). To our knowledge, the MEDSRA is the first attempt at integrating VGI into a location-based service for emergency decision support.

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## 2.2 Routing

The second major feature of the MEDSRA is a dynamic routing algorithm that can direct users to emergency shelter locations or to members of their DSN while taking into account hazard locations, road closures, and traffic congestion. Mobile connectivity allows for real-time vehicle management, which is essential for fast response to the quickly changing road conditions and unforeseen events that accompany many hazardous situations (Giaglis et al., 2004). Researchers have shown that a vehicle control system integrating GIS, GPS, and wireless communication can optimize routes and schedules for post office pick-up and delivery (Jung et al., 2006), and that geographic data may be used within a spatial optimization model or routing DSS to improve route safety during a disaster (Church and Cova, 2000; Keenan, 2008). One way to improve route safety is to dynamically re-calculate network edge weights based on traffic, road closures, and hazard locations, then obtain a good solution to the least-cost shortest path problem using heuristic techniques that are fast and require a relatively low level of computational resources (Schultes and Sanders, 2007). A compact road network data storage model coupled with a path finding algorithm that runs directly on the network without need for transformations can provide a memory and computationally efficient way of finding optimal paths on a mobile device (Zeng et al., 2006). A mobile service has been developed for finding the fastest subway route taking into account time and user location (Kim et al., 2009), and as computational and graphics capabilities improve it may be possible to extend landmark-based 3D emergency routing services to mobile devices (Neis et al., 2007).

## 2.3 Spatial Cognition

In addition to optimizing routing based on the physical configuration of the environment, it is important to consider how the spatial cognition of users will affect how they interface with MEDSRA. In other words, it must be cognitively engineered with the goal of maximizing ease of use (Raubal, 2009). This design goal is especially important for devices used during complex, dynamic emergency situations. It is well established that landmarks play a crucial role in how people understand and navigate their spatial environment (Montello and Freundschuh, 2005). As a result, the formalization of landmark semantics for location-based services has been an active area of research (Nothegger et al., 2004; Hansen et al., 2006). The routing algorithms used by MEDSRA will take into consideration the relative saliency of different landmarks for targeted user groups. In addition, the shortest or quickest emergency route may not be the best solution if the route directions are hard for the user to comprehend. The "simplest" path algorithm is one alternative designed to reduce the complexity of route instructions (Duckham and Kulik, 2003). Spatial cognition research can also be used to inform the user interface design of mobile routing applications (Kray et al., 2003). Mobile devices have limited screen real estate, and the organization of route map information on such systems should minimize cognitive load (Dillemuth, 2005).

## 3. FRAMEWORK

### 3.1 Problem Statement

Even the most well thought out decision support systems may suffer from flaws that can only be rectified through careful design and real world validation. To this end, we conducted a series of interviews with emergency management practitioners from several agencies in Southern California. The subjects of these interviews included California Department of Transportation (Caltrans) personnel, geospatial information specialists, and emergency management professionals from the campus to the county level. Interviews followed a semi-structured format, which allowed us to expand upon interesting topics while keeping focus on the subjects most relevant to developing a system that is easy to use and provides the necessary functionality. The interviews were often followed by impromptu tours of the subject's workplace, including facilities like a Caltrans Traffic Management Center (TMC), an Emergency Operations Center (EOC), several Geographic Information System (GIS) hardware and software installations, and an emergency shelter utilized during the 2009 Jesusita Fire. We choose to maintain the anonymity of our interview findings, but provide a list of subjects in the acknowledgements section of this paper. There are several findings that are especially relevant to our research:

- A mobile device-based system that provides consistent, reliable information could greatly assist emergency managers in decision-making. The ability to instantly locate personnel and share information within defined user groups could be very helpful, provided the system was reliable and easy to use.
- As of February, 2009 nearly 10,000 wireless devices have been registered with the University of California, Santa Barbara campus emergency alert system, which automatically sends text message alerts when hazards threaten the campus area. This suggests that many people may sign up for a voluntary hazard warning system such as MEDSRA, which will increase the likelihood of valuable VGI contributions.
- The City of Santa Barbara and the adjoining City of Goleta use different voluntary emergency notification systems, which may lead to inconsistent information dissemination to populations threatened by the same hazard. The MEDSRA could use data from the county or state GIS to ensure consistency of geoinformation across spatial and temporal scales.
- There is considerable debate concerning the extent to which official emergency information should be made public, but the fact remains that sometimes the best disaster information comes from TV crews or other public sources. Our system allows authorities to determine what official information is shared while also integrating information from unofficial sources.
- Integration of real-time traffic flow data into a GIS would be of great use to Santa Barbara County during both the planning and operational phases of emergency management. Major issues include the large percentage of the workforce that commutes to Santa Barbara from other parts of the county, thus leading to major differences in on and off peak traffic flow. The MEDSRA integrates real-time traffic data

into a simple, functional, and portable GIS that can be customized for emergency managers and other user groups.

- The Santa Barbara County emergency operations center (EOC) was moved when the Jesusita fire threatened its downtown location. Computers and other equipment had to be moved nearly 30 kilometers because there is insufficient funding for two fully operational EOCs, and there was an approximately one hour delay after the move before the phone lines were connected. A mobile device-based system may experience much less downtime, provided that the GIS server is located in a safe location and that backup generator-powered cellular or Wi-Fi networks are available.
- Updated maps were difficult to get early on in the Jesusita Fire, but the information flow got better as the event progressed. A tool that incorporates real time traffic information and the latest event maps would be very useful, especially if it could be used in conjunction with the radios already installed in staff vehicles. The MEDSRA framework could be incorporated into existing radio or GPS systems already used by first responders or emergency managers.
- Although the County of Santa Barbara used a Google Map to display information during the fire, it was difficult to ensure accuracy and maintain this map along with other more pressing duties. It is very important to strike a balance between VGI and official sources information so that the public stays informed but people are not overwhelmed and

confused by conflicting information. This balance is increasingly important as traditional information sources such as television and radio continue to lose ground to the Internet and mobile devices.

### 3.2 Functions

The MEDSRA system architecture is shown in figure 1. The user must first download and install the application, then register by providing a unique user name, valid email address, and password. Next is the option to define a disaster support network (DSN) which is designated by providing the user names of other people registered on the system. These users are then emailed and must indicate their acceptance to become part of the DSN. The application starts when clicked by the user, or alternatively can be started automatically upon receiving a specially encoded text message sent by a local emergency alert system. Our user interface is designed for ease of use, with large buttons and a touch-screen interface. The initial screen shows the user's current location on a map as determined by the GPS chip contained within the device, along with current hazard perimeters, road closure, and evacuation zone locations provided through a wireless connection to a remote GIS server. Along the bottom of the screen are three buttons indicating the primary functions of the MEDSRA system: Locate, Communicate, and Route (figure 2).

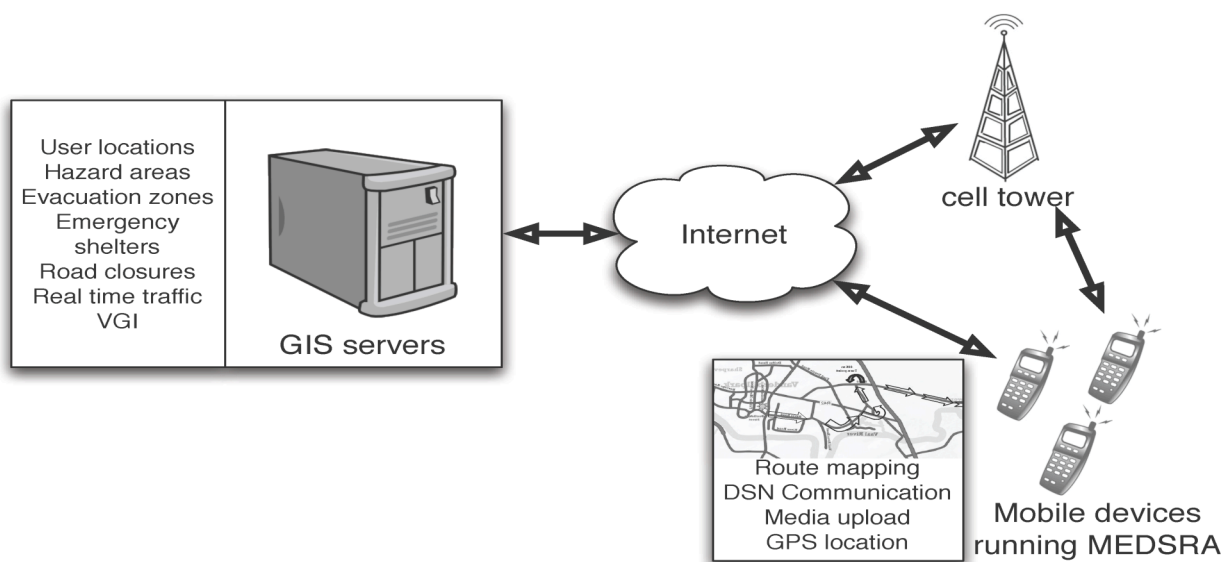


Figure 1. MEDSRA system architecture.



Figure 2. Startup screen shows user's location (star). Cross-hatched area shows the Jesusita Fire location.



Figure 3. Locate function shows the locations of people in the user's disaster support network (triangles).

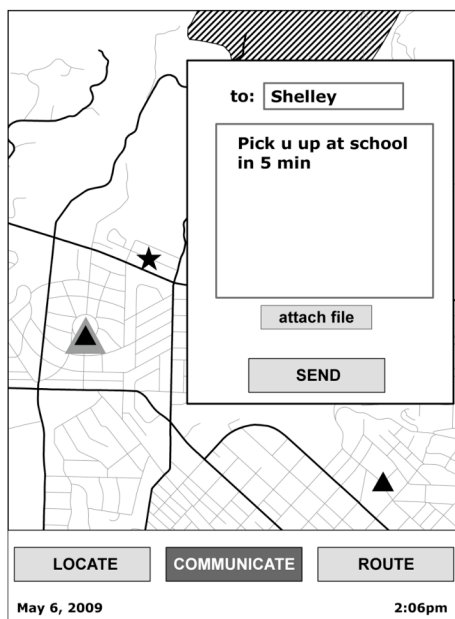


Figure 4. User can send text or media to other members of their DSN or the entire MEDSRA user base with the communicate function.

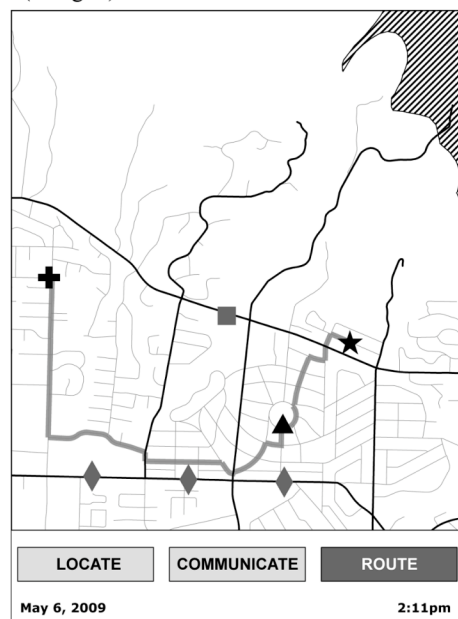


Figure 5. Route function guides user to Shelley's school and to the emergency shelter (cross), automatically accounting for road closures (square) and traffic congestion (diamonds).

**3.2.1 Locate:** The Locate function adds the locations of all DSN members to the initial map (figure 3), with special icons to indicate if a DSN member has contributed VGI to the system. Alternately, the Locate function can be used to view icons indicating all VGI content posted by users of the MEDSRA, if this content was posted with explicit consent to be viewed by any system user. This may be useful in the early stages of a hazardous event when people may be unable to obtain the information they need through their DSN or official sources. A user can simply touch a contributing user's icon to access posted VGI, which is stored on the remote GIS server.

**3.2.2 Communicate:** The Communicate function allows the user to post text, pictures, or video that is accessible to either their DSN or all users of the MEDSRA system. The screen switches from map view to a simple text entry interface that also allows for upload of media stored locally on the mobile device (figure 4). These media are stored on the active GIS server for a pre-specified time period, then catalogued in long term storage with all identifying information removed in the interest of protecting the communication privacy of users while maintaining researcher access to the potentially rich dataset. An encoded text message is sent to DSN members who do not have the application running that will alert them that new VGI has been posted and automatically launch the MEDSRA on their device.

**3.2.3 Route:** The Route function uses an advanced vehicle routing algorithm to find an optimal path, taking into account the unique path constraints often prevalent during a disaster (figure 5). Such path constraints include the locations of road closures, evacuation zones, and the hazard itself, as well as real-time traffic conditions all of which are stored the GIS server. The user can simply click a starting location and one or more destinations on the map, or enter these locations through a text-based address matching interface. The unique feature of this routing function is that it can run directly on the mobile device, rather than relying on a wireless connection to a central server. A compact data structure is used to store the road network attributes and locations that were most recently transferred to the device memory. This allows the Route function to operate even if the wireless signal is lost, which may occur during an emergency when existing network capacity is exceeded or cellular infrastructure is damaged or destroyed.

## 4. CONCLUSIONS

### 4.1 Limitations

Uncertainty over the role of VGI during hazards and disasters presents a unique challenge to decision support system designers. Ensuring data quality is paramount for system users who may use the MEDSRA to inform critical decisions during an emergency, thus inaccuracies in user-generated content should be minimized. We believe that an open system architecture will enable self-policing of content by users, and that the near-instantaneous integration of data from a variety of sources may actually improve upon information traditionally provided by government and media. It is important to note that MEDSRA users cannot directly modify the GIS layers that enable the locate, communicate, and route functions, and that all VGI will remain hidden until

a user touches the map icon representing another user who has posted content.

Our system is also constrained by the availability and reliability of underlying technologies. We assume that all potential users have access to a GPS and touch screen enabled mobile device with enough memory and processing power to perform system functions. The reliability of cellular networks is also an issue: at times during the Jesusita fire the cellular network was incapacitated in parts of Santa Barbara due to insufficient bandwidth. Generator-powered portable cellular systems and Wi-Fi networks may alleviate this problem for small areas and specific user groups, and we believe that future improvements in cellular network reliability, capacity, and speed will improve MEDSRA functionality moving forward.

### 4.2 Future Research

A planned research project is the development of a prototype MEDSRA system built using the Google Android software stack. The Android platform is a Java based, open source operating system and application programming interface (API) for mobile devices, which allows one to leverage existing social networking and VGI tools (e.g., Google maps API) as well as global positioning system (GPS) and magnetic compass hardware. The development of a prototype will allow us to research the efficacy of various routing algorithms and user interface designs.

Future work includes extending the routing algorithm to allow for multi-modal evacuation, routing users on foot, by bicycle, and by bus or other mass transit. Similar decision support applications could be developed for user groups such as emergency managers or fire fighters that allow for display of advanced operational GIS data (utility lines, cadastral layers, etc) or incorporate sensors for smoke, heat, or relative humidity into the device itself. Validation through agent-based modelling and extensive field testing is essential before systems such as the MEDSRA are implemented during an actual disaster.

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