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RAPID OBSERVATION OF VULNERABILITY AND ESTIMATION OF RISK (ROVER): END-TO-END SEISMIC RISK MANAGEMENT SOFTWARE

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ABSTRACT

Owners of building portfolios in earthquake country have several data-related seismic risk mitigation concerns: Before an earthquake, they need to know the locations and seismic characteristics of their buildings to know which might pose a potential seismic risk. They also need the ability to assess and prioritize risk-mitigation efforts, and to develop emergency response plans. Immediately after an earthquake, they need to know which buildings were most likely damaged to prioritize inspections, so as to mitigate the fatality risk in aftershocks, and may need to manage and perform the safety inspections. The US Federal Emergency Management Agency has developed a suite of software to assist that effort: Rapid Observation of Vulnerability and Estimation of Risk (ROVER) is free, open-source mobile software for building owners and risk managers to use to inventory buildings at risk from future earthquakes, monitor or analyze them for future seismic risk, and manage and perform post-earthquake safety assessments. Unlike paper forms (FEMA 154 and ATC-20), ROVER handles much of the data automatically, providing geolocation, automated soil and hazard lookup, watermarked digital photos, a web-accessible database, all controlled and managed by the user. ROVER integrates pre- and post-earthquake data with other risk-management software ShakeCast and HAZUS-MH. ROVER is free, with no licensing costs. It is open-source software, with human-readable source code available for examination and modification by co-developers, two of whom have already come forward, even before the software has been released. The software has been thoroughly tested and is endorsed by prominent members of the earthquake risk-mitigation community, building department officials, a state legislator, and other earthquake risk thought leaders.

Introduction

Owners of large numbers of buildings in earthquake country need information regarding building location, use, seismic attributes and seismic risk. They may have due-diligence requirements to understand and inform occupants of seismic risk. If they have mitigation or planning resources, they need to know which buildings are most likely to experience damage so they can prioritize detailed assessments, mitigation and planning measures. In the immediate

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aftermath of an earthquake, they need to know which buildings were most likely damaged, and then very rapidly gather field observations of that damage. They may manage and perform post-earthquake inspections themselves, and need to keep abreast of inspection progress and outcomes. They may perform HAZUS-MH risk analysis of their buildings, or ShakeCast monitoring, both of which require building information to avoid garbage-in-garbage-out problems.

Many building owners use two de facto international standards in pre- and post-earthquake rapid risk screening: FEMA 154 (Applied Technology Council 2002) and ATC-20 (Applied Technology Council 1989 etc.). These are paper-based methodologies, whose advantages are many and are not thoroughly listed here. Key among them however is their speed and simplicity (10 minutes or so per building, with 1-2 page forms), broad support and use (FEMA 154's 2002 update names 21 contributors, including several industry leaders, and has probably been used on 10,000s if not 100,000s of buildings; ATC-20 has probably been used on 100,000s if not millions of buildings), and well established training infrastructure.

But paper-based forms for earthquake risk management have their limitations, key among them (at least those relevant here) being: transcription effort and errors; weak connection to photographic support; lack of a preexisting electronic database; geolocation challenges; volume and storage challenges (which leads to the loss of raw data); duplication cost; disconnect from hazard and soil databases; and disconnect from other electronic risk-management tools such as HAZUS-MH (NIBS and FEMA 2009) and ShakeCast (Wald et al. 2008). Software developers have in the past attempted with varying degrees of success to automate both ATC-20 and FEMA 154. ATC itself developed the Palm-based software ATC-20i, and a tablet-based version of FEMA 154 was developed by Wang and Geottel (2007), which overcome several of these challenges.

In part because the ATC-20i software relied on a now-defunct operating system, the Applied Technology Council, with the support of the Federal Emergency Management Agency, set out to remake mobile software for pre- and later post-earthquake rapid visual screening of buildings for seismic risk. A release-ready version 1.0 of the resulting software is now awaiting final FEMA approval. The software, called Rapid Observation of Vulnerability and Estimation of Risk (ROVER), has as some of its version-1.0 objectives, the following:

- Free software with no requirement of licensed supporting software
- Open source, i.e., the human-readable source code is available for scrutiny and enhancement
- Client-server architecture, with an unlimited number of field units (clients) able to gather field data and synchronize their data by a variety of means with a central database server
- Client operates on a low-cost smartphone with a common, long-lived operating system
- Client need not have Internet or phone service
- Database server can operate on a variety of operating systems
- Field observations tightly bound to latitude and longitude, digital photos, digital sketches
- High degree of fidelity to FEMA 154 and ATC-20 forms and methodology
- Pre-earthquake data available during post-earthquake data collection
- Comply with best practices of object-oriented programming; clear user and developer documentation and robust application programming interface
- Data exportable to HAZUS-MH Advanced Engineering Building Module

- Tight integration with ShakeCast: FEMA 154 data readily imported to ShakeCast; ShakeCast damage estimates automatically inserted into ROVER server database
- User maintains secure control of all data at all times, i.e., no need for data hosting by others

Development Process

FEMA funded the Applied Technology Council to implement FEMA 154 on mobile software beginning in 2005. A project review panel was created, comprising the original developer of FEMA 154, as well as several FEMA officials and other experts. It determined that the next step was to determine users' needs. A user needs assessment was then performed that examined a variety of hardware and software choices, and selected among them. These include, among other issues: operating systems, geographic position information, photos and sketches, database choices, site-specific soil and hazard databases, integration with municipal databases, HAZUS-MH, site-specific calculation of basic structural hazard (BSH) score, and an enhanced (frequency-probability) interpretation of the risk score S. The user needs assessment also specified system use cases (step-by-step examples of how a user might actually interact with the software) and system requirements in sufficient detail that a software programmer could create the software with limited additional supervision.

As the work progressed, it became clear that it would be straightforward and desirable to add the capability to perform the ATC-20 rapid or detailed post-earthquake field data collection using ROVER. We also added an application programming interface so that other software could readily access the ROVER database without the risk of corrupting it and without needing to know the database schema, which in any case might change over time. This then enabled the development of a component called RedROVER (named after the US children's game Redrover: "Redrover, Redrover, send your data over.") that exports ROVER data to HAZUS-MH's Advanced Engineering Building Module. It also enabled integration with ShakeCast, the US Geological Survey's free software that monitors in near-real-time a user-defined list of facilities for potentially damaging earthquakes, and informs the user of likely damage. In collaboration with the ROVER development team, the ShakeCast developers created a special version of ShakeCast that draws in the ROVER data and then sends alerts back out to the ROVER server estimates of post-earthquake safety tag colors. Other potential co-developers have emerged as the software developed and we discussed it with others in the earthquake engineering community.

A Common System Use Case

Perhaps the easiest way to understand ROVER is through a system use case: a description of one scenario, one particular sequence of events in which a particular user might employ ROVER. Other system use cases are possible, but this one seems likely.

1. Administrator formats an existing database of buildings of interest according to the ROVER API, and makes the API call that causes the ROVER server to import the database. This populates the server database with a subset of the FEMA 154 fields, such as address, square footage, etc.
2. The administrator accesses the server via a web-browser interface and assigns each

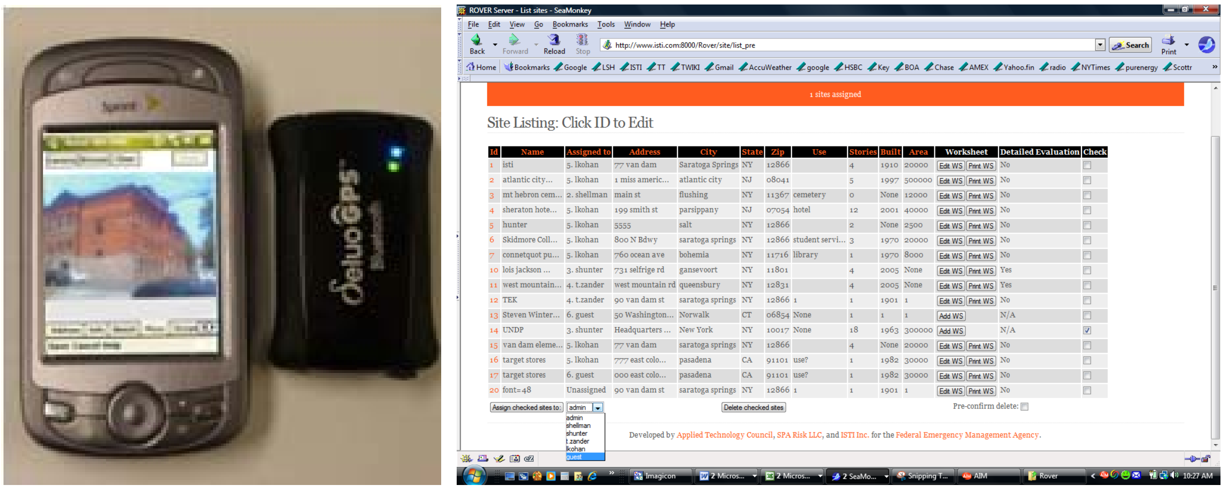
building to one field inspector. Fig. 1 shows an example screen in the server user interface.

3. Inspector starts the ROVER client on a smartphone (Fig. 1), and using the client's user interface, synchronizes the client with the server, either via wire connection of the client to the server, or via the smartphone's WiFi connection to the server's local area network, or via the smartphone's WiFi or telephone data connection to the Internet. This causes each client to download a list of buildings assigned to that inspector. The inspector's name and other credentials have previously been entered into the client's settings.
4. Inspector selects pre-earthquake screening from the list of options, and sees a color-coded list of buildings (Fig. 2a): pink for buildings that have been assigned but not yet examined, green for buildings that have been examined but not yet synchronized with the server, and gray for buildings that have been examined and whose data have been synchronized with the server.
5. Inspector goes to the site of a building on the list that has not yet been examined and starts a Bluetooth GPS device that has been previously paired to the smartphone.
6. Inspector chooses to edit the form associated with that site, with address and other optional information already filled in. The full-page FEMA 154 form is displayed in the small smartphone screen with tabs, each tab containing a portion of the form (Fig. 2b).
7. Inspector enters or edits building identifying data (building name, address, city, state, ZIP). Inspector stands at front door of the building and taps a button labeled "Now standing at front door." The latitude and longitude are automatically acquired from the GPS device via Bluetooth radio and filled in on the data form.
8. Inspector taps "Info" tab, and using drop-down lists, selects number of stories, approximate year built, and enters total square footage, other identifiers and the building's use, using the phone's physical keyboard or on-screen soft keyboard (Fig. 2c). Inspector taps the "Occupancy" tab and selects the occupancy category and the approximate number of occupants. Inspector similarly enters soil type (which, alternatively, can be filled in automatically by the server using its built-in national soil map), and other site hazards, on other tabs.
9. Inspector taps "Scoring" tab and selects one or more model building types that this building may be (Fig. 3a). There are 15 model building types, reflecting different combinations of construction material and lateral force resisting system. Inspector also taps any obvious performance modification characteristics, such as vertical or plan irregularity such as soft story or L-shaped plan. A risk score is calculated for each possible building type, based on a slightly enhanced version of the basic FEMA 154 scoring system.
10. Inspector taps the "Eval" tab, enters any additional comments, and optionally changes the "Detailed eval required" checkbox, which is automatically checked if the lowest score is less than 2.0, or other threshold previously entered in the software settings.
11. Inspector taps the "Sketch" tab, and draws a sketch of the building layout.
12. Inspector taps the "Photo" tab, and snaps one or more digital photos of the building, each with optional caption (Fig. 3b).
13. Inspector taps "Save." The record is saved as an XML file on the smartphone.
14. Returning to the list of assigned buildings, the inspector navigates to other sites and repeats the data-collection process.
15. Inspector synchronizes the smartphone's database with the server, using any of the 3

methods previously mentioned. If the smartphone has an active data plan, this can be done on the fly, at any time, which sends any new data to the database server. The server automatically integrates the new records into its database, including adding a watermark to each photo with building name, inspector ID, date, time, latitude and longitude (Fig. 4b).

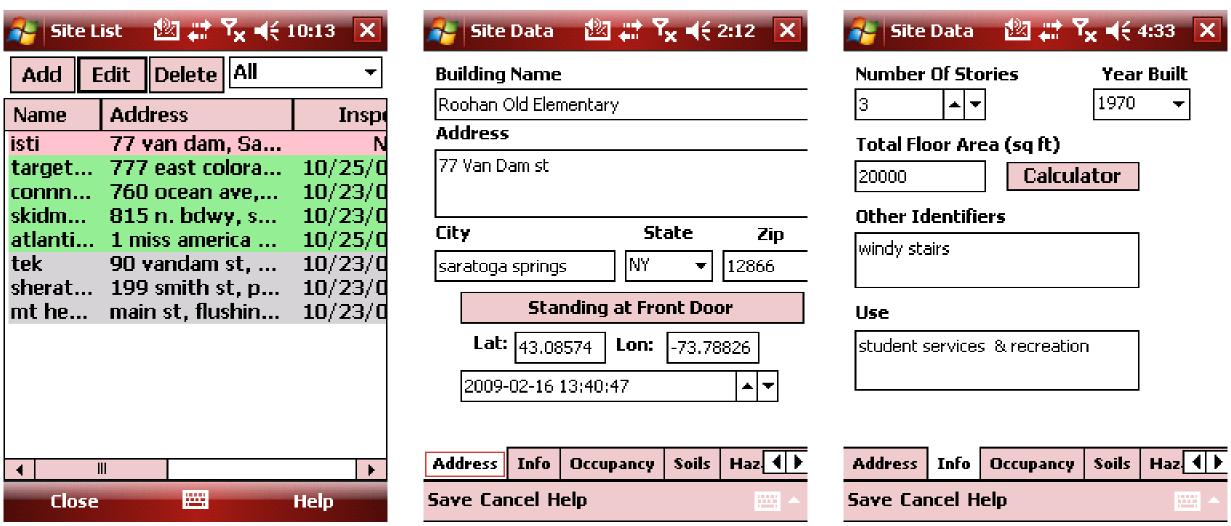
16. Administrator examines field records in the server's web interface, optionally changes field entries, optionally instructs ROVER to automatically look up and update soil-type assignments and seismic hazard using ROVER's built-in soil and hazard databases. These are taken from the Wald and Allen (2007) gridded, topographically derived soil map of the world, and from the US Geological Survey's National Seismic Hazard Mapping Program's gridded seismic hazard map of the United States.
17. Administrator starts ShakeCast ROVER edition and presses the button that causes ShakeCast to import the ROVER database. ShakeCast will now automatically monitor the locations of the facilities for potentially damaging earthquakes.
18. Administrator optionally prints pre-earthquake risk assessments or exports the data to XML files, which risk managers use to select buildings for detailed safety evaluations, which then may lead to risk mitigation.
19. An earthquake occurs. ShakeCast automatically estimates ATC-20 safety tag color of all affected buildings, and sends the estimated safety tag colors to the ROVER server, which then inserts them into the database. They are indicated in the database as having been generated by ShakeCast.
20. Inspectors, having been informed of the occurrence of the earthquake (ShakeCast can optionally email them or inform them of the earthquake by text message), turn on their smartphones, synchronize the client with the server using any of the methods previously mentioned, and now possess the estimated safety tag colors of the buildings assigned to them.
21. Inspector acquires copies of the ATC-20 red, yellow, and green paper placards, plus tape and all other necessary supplies for post-earthquake safety assessment, navigates to a building in the assignment list and carries out a rapid or detailed safety assessment of the building, filling in the ATC-20 forms on the client rather than on paper (Figs. 3c and 4a). The steps are not detailed here, but they are similar to the pre-earthquake FEMA 154 process. Data from the FEMA 154 pre-earthquake process have been pre-populated on the ATC-20 forms.
22. Inspector tapes the appropriate safety tag to the building, optionally synchronizes the client's database to the server, and proceeds to the next assigned building.
23. Suppose the inspector has a phone with an active data plan, and while in the field is uncertain of which tag to assign. Suppose also that the administrator has set up the server to be web-accessible, i.e., it has an IP address that is visible from the web. Inspector completes an assessment, synchronizes with the server, and then telephones an expert who has been preauthorized to examine the data.
24. The expert, located anywhere in the world, logs onto the server, selects "View list of sites and assignments," selects the building in question from the list of available building records, and views the photos, sketches, and other data the inspector has entered and uploaded to the server. The expert provides advice or other instructions to the inspector, who can then modify the building record on the client to finalize the tag color.
25. Administrator optionally prints post-earthquake safety inspection reports

26. Administrator optionally exports the field inspections to Google Earth KML format, and displays or examines them in Google Earth.
27. In the weeks and months after the earthquake, as building permitting and repairs proceed, the administrator updates the post-earthquake safety inspections.



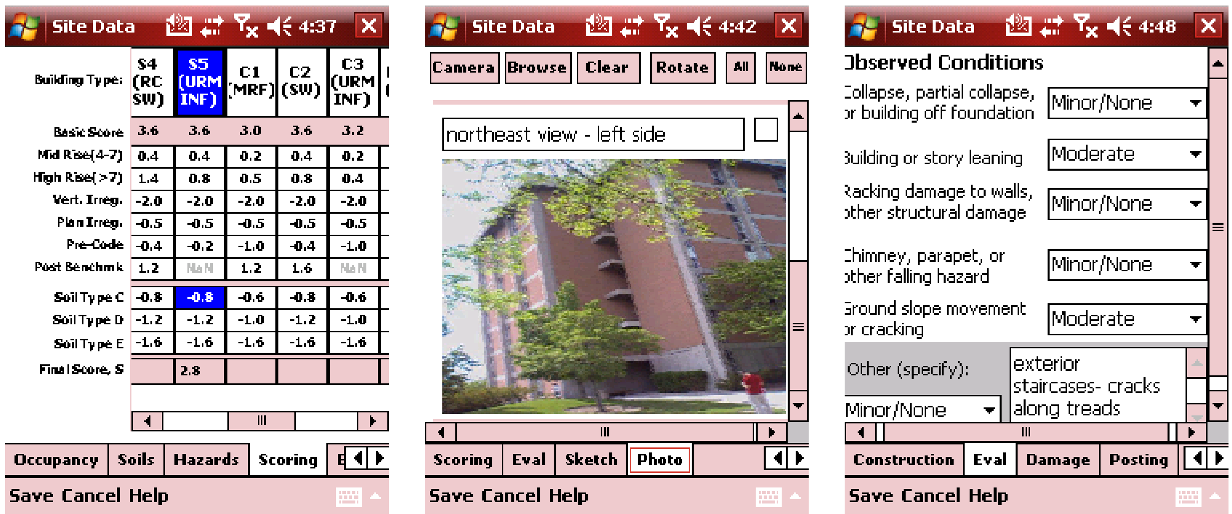
(a) (b)

Figure 1(a). Client hardware: a Windows Mobile smartphone and a Bluetooth GPS device. The external GPS is required for accuracy and because onboard GPS chipsets are often inaccessible to 3rd party software. The server hardware (not shown) is a Windows, Mac, or Linux PC. (b) The server is accessed by a common web browser. Here, sites are being assigned to inspectors via the web-browser interface.



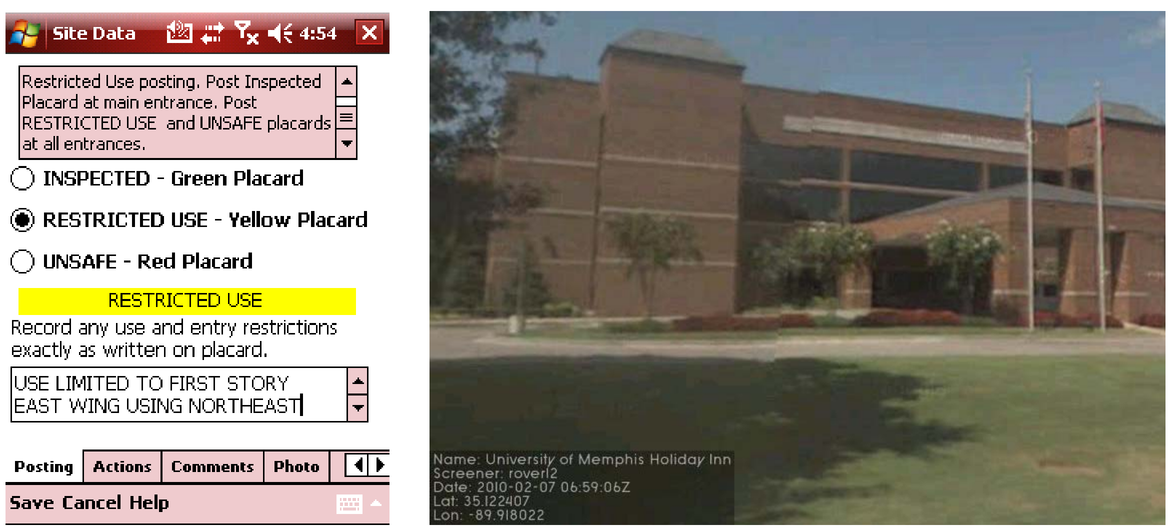
(a) (b) (c)

Figure 2(a). The site list on the client: pink for assigned, green for inspection completed, gray for data uploaded to server. (b) Full-page paper forms are broken into tabs; here is the address information with GPS location. (c) Wherever possible data are entered by dropdown boxes, but there are several fields for free-text entry.



(a) (b) (c)

Figure 3(a). Pre-earthquake (FEMA 154) scoring tab is completed by tapping on the possible structure types (column headers) and modifiers (cells). (b) User can take an arbitrary number of photos with the phone's onboard camera, and add captions. It is virtually impossible to fill the onboard phone storage in days or even weeks of operation. (c) A screen in the post-earthquake (ATC-20) inspection form. All pre-earthquake data are available in the post-earthquake form, reducing data-collection effort.



(a) (b)

Figure 4(a). "Posting" section of the post-earthquake (ATC-20) inspection form. (b) When uploaded to the server, photos are watermarked (lower left-hand corner) with building name, inspector ID, date, time, and latitude and longitude.

Technology

System use cases like this were created to inform the design and coding of ROVER. Several technological breakthroughs facilitated the actual software programming. First, the recent explosion in the availability and use of smartphones and GPS technology has made it practical to gather, record, and synchronize field data on the fly, including digital photographs, geolocation, etc. Free, robust software development kits for common smartphone operating systems have led to a vast pool of programmers able to create the necessary code. The upsurge in the use of open-source software, exemplified by the Linux operating system and the Python programming library, has empowered a developer community with resources to create new code from pre-existing, free code components. Tools like ROVER can now be created without purchasing site licenses for any of the necessary software components.

The software developer, Instrumental Software Technologies, Inc., created the ROVER client software to operate on a Windows Mobile Smartphone (touchscreen, Bluetooth and OS version 5.0 or newer). The ROVER client is written in the Microsoft C# programming language, which is Microsoft's .NET version of Java. The server is a database and interface to it operating on an ordinary Windows (XP or newer), Mac or Linux desktop or laptop computer. The ROVER server is written the Python programming language, which is a platform-independent language that allows the server to be deployed to many supported computer operating systems. Both client and server are written entirely using open-source software.

The software was alpha- and beta-tested throughout development. A pilot test in May 2008 at the University of Utah demonstrated the viability of the pre-earthquake module. This pilot test was carried out by invited participants from local building departments, engineering and architecture students and professors, fire department officials, and others, who provided generally positive feedback that was then used to enhance the software. A second series of pilot tests was carried out by inspectors of the Los Angeles Unified School District, as part of their participation in the Great Southern California ShakeOut exercise of November 2008.

Thought leaders such as Dr Lucy Jones of the US Geological Survey, Doug Bausch of the Federal Emergency Management Agency, and earlier developers of FEMA 154 software such as Yumei Wang, have participated in aspects of the development or testing of the ROVER software, and support its use. Laurence Kornfield of the San Francisco Department of Building Inspection, and David Wald of the US Geological Survey, likewise have examined and support the use of ROVER. Although we have developed user training materials, at least one user found the software to be so intuitive that special training on the software seems unnecessary (David McCormick, pers. comm., Feb 2010).

ROVER in Business Practice

Some other features of ROVER are of interest and worthy of note. First, when FEMA ultimately authorizes the release of ROVER, it will be free, with no licensing fee. It should ultimately save the user time and expense relative to a paper-based approach to FEMA 154 or ATC-20. We estimate that the avoided work of creating a database, transcribing paper forms, geolocating sites, and linking digital photos and other data to the inspection database, saves staff labor on the order of 10 minutes per building. At an average labor cost of say $75/hr, creating a database with ROVER would save a building owner $12,500 per 1,000 buildings. The hardware required to carry out the inspections costs on the order of $200 per kit (for the smartphone and Bluetooth GPS device), so to equip an inspector taskforce of perhaps 10-20 people would cost on the order of $2,000 to $4,000, roughly equivalent to the cost of a single site license of ArcGIS. The labor savings would therefore offset the hardware cost with a benefit-cost ratio (BCR) of perhaps 4:1, commensurate with other cost-effective natural-hazard mitigation efforts. The BCR would increase with the number of buildings inspected.

ROVER provides some unique functionality. There are no other software packages of which we are aware that serve this end-to-end suite of earthquake risk-management objectives. Users have expressed appreciation of the automated watermarking of photos, which has uses outside pre- and post-earthquake risk management. They like the intuitive user interfaces and ease of use of the smartphone as a data-collection platform, because of its compact size, built-in camera, and the ability to use it all day. Several potential users have expressed appreciation that the software is to be free, open source, and adaptable to needs that they regularly face.

Other users have noted the potential value of real-time control of post-earthquake safety inspections (e.g., Laurence Kornfield, pers. comm.., Dec 2009). They have noted the value of implementing the de facto standards FEMA 154 and ATC-20, ROVER's low cost of ownership, and the 3rd party support of HAZUS-MH, USGS ShakeCast, and the linkage with established ATC-20 and FEMA 154 training materials.

Conclusions

ROVER is free, open-source software for building owners and risk managers to use to gather inventory data, inform risk-mitigation decisions, and improve their earthquake monitoring and response processes. Unlike existing paper-based and electronic solutions, ROVER is an efficient, end-to-end solution that saves labor and prevents data loss; enables remote data access and near-real-time process control, and integrates pre- and post-earthquake safety assessment processes along with catastrophe risk modeling and real-time earthquake monitoring. ROVER was developed in collaboration with several of the same people who created and train users on ATC-20 and FEMA 154. The ShakeCast ROVER edition was created by the developers of ShakeCast. For all these reasons, the software development team anticipates that the ROVER software will be of value to a wide variety of users, such as building departments, school districts, various entities in FEMA and the Department of Homeland Security, county and state emergency managers, and owners of large numbers of buildings such as banks, telephone companies, and real estate investors.

Acknowledgments

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Otto, Neville Pereira, Larry Reaveley, Cyril Ryan, Hal Schechner, Bob Spears, Yumei Wang, and Barry Welliver. ShakeCast is a product of the United States Geological Survey (David Wald Project Manager and Kuo-Wan Lin Lead Programmer).

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