Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1826

Role of Technology in Developing and Recommending Earthquake Alerting Protocols

Doug Bausch[1] and David J. Wald[2]

Abstract

FEMA and the USGS have coordinated on the development of new products that support automatic alert levels that are intended to be used in the first few hours of an earthquake response. Specifically, we have worked to ensure that the new Earthquake Impact Scale associated with the loss*PAGER* system corresponds with recommended activation levels for FEMA. For the first time, we are able to move from just using magnitude thresholds to actionable assessment information. These advancements are, in part, due to improvements in earthquake science as well as by the implementation of this new research in the delivery of earthquake information. In this article we provide a brief update on recent and ongoing developments of earthquake information tools, and provide the necessary background on the improvements in rapid loss estimation and new alerting protocols.

We first describe how responders, critical lifeline utilities, companies, the media, and individuals can be automatically alerted and use enhanced post-earthquake information to move beyond just epicenter and magnitude in making response decisions. We then show how rapid shaking maps, combined with population exposure and vulnerability can allow for rapid loss estimates. Though such loss estimates are only approximate, they provide a necessary prerequisites for an Earthquake Impact Scale and for setting predefined alert levels. Because these are calibrating against response experiences and activities from past earthquakes, the Earthquake Impact Scale is specifically correlated to recommended alert levels that can be used for activating pre-scripted response activities in a much more timely fashion than could be done in the past.

USGS ANSS Products Overview

The U.S. Geological Survey (USGS), under the auspices of the Advanced National Seismic System (ANSS), is continuing to develop new and improved tools for post-

---

[1] FEMA

[2] USGS

earthquake information and response. Existing tools range from passive, web-based post-earthquake information content requiring no pre-event configuration to sophisticated damage-assessment and active notification systems (i.e., *ShakeCast*, described below) that require pre-event set up, IT expertise, and a knowledge of one's inventory's vulnerabilities.

Recent Earthquake Maps. For most users, web-based earthquake products and maps provide the starting point for earthquake information. Users typically become aware of an earthquake, get online, and there one can fine detailed USGS maps and summary information about any significant earthquake. The Recent Earthquakes web pages provide general background as well as direct links to additional information and products. This passive approach requires only a simple web search or using prior bookmarks. Automatic receipt of earthquake information requires only slightly more homework.

Earthquake Notification Service (ENS). Customizable alerts—earthquake magnitude and location notifications—are provided with *ENS* (*Earthquake Notification Service*), adding active alerting to rapid earthquake information products available via USGS Web Pages. *ENS* provides the alerts for earthquakes both domestically and internationally, and can be customized to receive specific events by location, magnitude, and time of day; users can also specify multiple email or wireless addresses for receipt of notifications.

While higher magnitude earthquakes have greater energy release and can potentially affect a much larger area, losses depend directly on the exposure and vulnerability of a population to specific levels of shaking. Both the shaking and the built (populated) environment can take vary complicated patterns, so a clear image of the potential impact may not be obvious. For example, events in remote or rural areas of large magnitude may be of less impact than a much lower magnitude event in large, vulnerable metropolitan area. Likewise, shaking intensity extends over greater areas in the Eastern US than in the West. These complexities, and the poor correlation of earthquake magnitude and impact require moving beyond just magnitude and location for informing response decisions.

ShakeMap: Moving Beyond Magnitude and Location. *ShakeMap* is a tool used to portray the extent and distribution of potentially damaging shaking following an earthquake by combining recorded seismic shaking levels with state-of-the are shaking estimates. The rapid availability of these maps is of particular value to emergency response organizations, utilities, insurance companies, government decision-makers, the media, and the general public. The essential component of *ShakeMap* is that it provides a map of the spatial variations of shaking intensity, indicating areas most strongly shaken in simple visual patterns in map view. While magnitude has been traditionally used for indicating earthquake size, earthquake strength is better described as it varies from place to place using macroseismic intensity (e.g., Modified Mercalli Intensity) which describes how shaking was experience as well as the effects of the earthquake on the built environment. For easy, rapid assessment of the shaking pattern *ShakeMap* portrays color-coded macroseismic intensity.

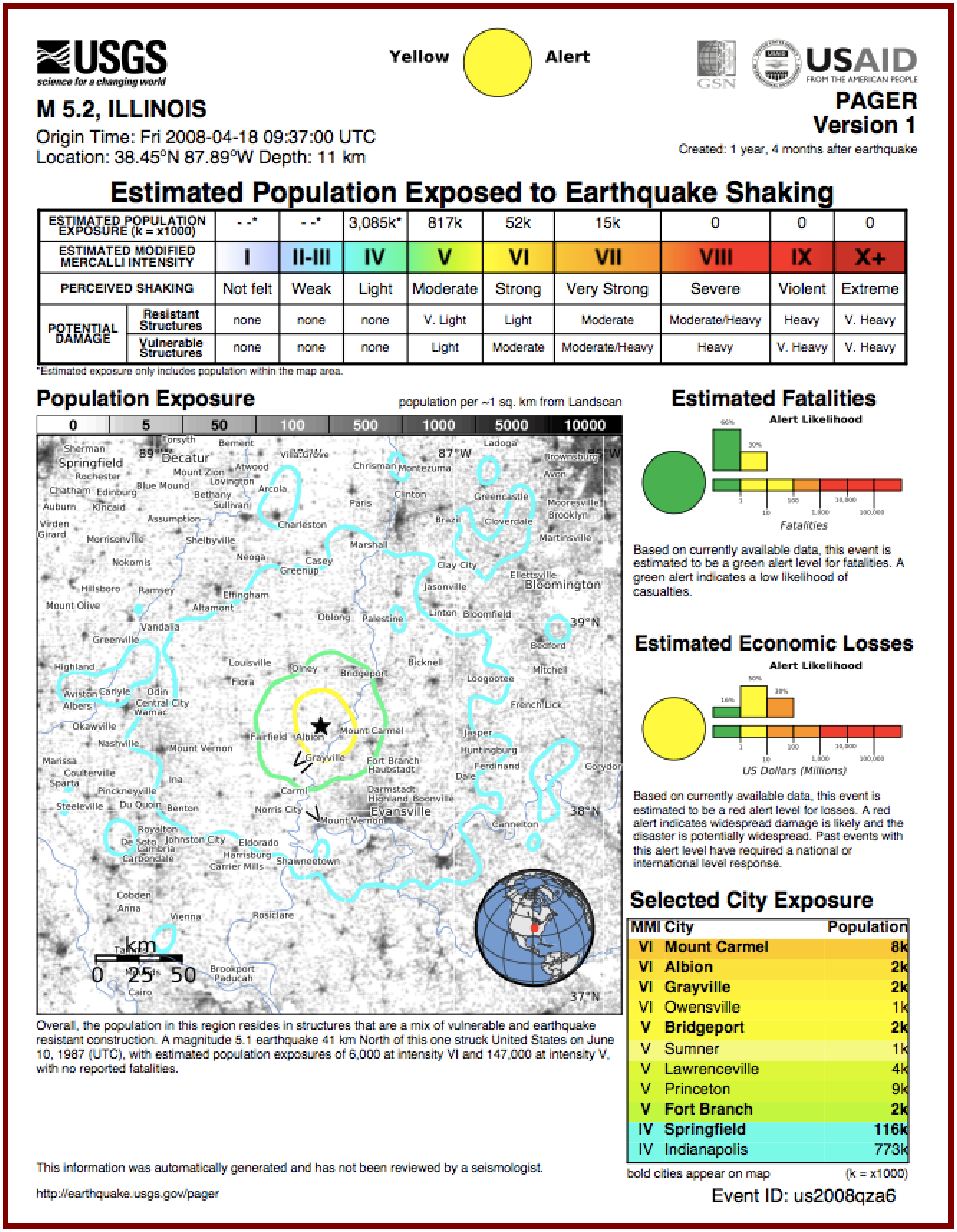
Across much of the country, particularly in the Central and Eastern US, *ShakeMap* is augmented by incorporating macroseismic intensity data directly from the USGS "*Did You Feel It*?" (*DYFI*?) system. *DYFI* is an automatic web-based system for rapidly generating seismic intensity maps based on shaking and damage reports collected from internet users immediately following earthquakes. The popularity of *DYFI* assures high quantities of responses for any significant domestic earthquake, and such quantity of data allows for robust intensity observations and constraints for *ShakeMap*.

ShakeCast: Automatic use of ShakeMap for Critical Facilities and Utilities. When a potentially damaging earthquake occurs, utility and other lifeline managers, emergency responders, and other critical users have an urgent need for information about the impact on their facilities so they can make appropriate decisions and take quick actions to ensure safety and restore system functionality. Building off the *ShakeMap* system, *ShakeCast*, short for *Shake*Map Broad*cast*, is a fully automated system for retrieving specific *ShakeMap* products to critical users and triggering established post-earthquake response protocols (Wald et al., 2008a). *ShakeCast* allows utilities, transportation agencies, and other large organizations to automatically determine the shaking value at their facilities, set thresholds for notification of inspection priorities (or damage levels; typically damage unlikely, moderate, or serious) for each facility, and then automatically notify (via pager, cell phone, or email) staff within their organizations who are responsible for those particular facilities so they can prioritize their response.

For many critical lifeline and transportation groups, particularly in the western US, *ShakeCast* has replaced the notion of drawing a circle on a map around the epicenter for initiating inspections. Since the shaking pattern is complex, and the vulnerability of infrastructure varies greatly, *ShakeCast* can greatly increase the accuracy of post-earthquake inspection prioritization over simplified approaches.

PAGER: Adding Population Exposure and Vulnerability. Neither earthquake magnitude nor macroseismic intensity provides sufficient information to judge the overall impact of an earthquake. The last, vital ingredients in ascertaining the impact of an earthquake are i) the population exposed at each intensity level, and ii) how vulnerable that population is to building damage (which is dominated by the degree of seismic resistance the local building stock).

The new *PAGER* (*Prompt Assessment of Global Earthquakes for Response*) system, takes a *ShakeMap* as the primary shaking input. Then, based on a comprehensive population database, *PAGER* computes the population exposed to each shaking intensity. Finally, *PAGER* uses simplified loss modeling approaches to quantify both the human and economic impact (Wald et al., 2008b). Losses are computed by combining shaking, exposure, and vulnerability calibrated against damages from past earthquakes in the region (Jaiswal et al., 2009). With this approach, *PAGER* now automatically identifies earthquakes that will be of societal importance, well in advance of ground-truth or news accounts, and now plays a primary alerting role for domestic as well as global earthquake disasters (*Figure 1*). *PAGER* can now easily be found on the USGS earthquake event web pages and critical users can subscribe to alerts by contacting USGS.



USGS
science for a changing world

Yellow Alert

USAID
FROM THE AMERICAN PEOPLE

GSN

M 5.2, ILLINOIS

Origin Time: Fri 2008-04-18 09:37:00 UTC
Location: 38.45°N 87.89°W Depth: 11 km

PAGER Version 1

Created: 1 year, 4 months after earthquake

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	3,085k*	817k	52k	15k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000

Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. A magnitude 5.1 earthquake 41 km North of this one struck United States on June 10, 1987 (UTC), with estimated population exposures of 6,000 at intensity VI and 147,000 at intensity V, with no reported fatalities.

Estimated Fatalities

Alert Likelihood

Fatalities

Based on currently available data, this event is estimated to be a green alert level for fatalities. A green alert indicates a low likelihood of casualties.

Estimated Economic Losses

Alert Likelihood

US Dollars (Millions)

Based on currently available data, this event is estimated to be a red alert level for losses. A red alert indicates widespread damage is likely and the disaster is potentially widespread. Past events with this alert level have required a national or international level response.

Selected City Exposure

MMI	City	Population
VI	**Mount Carmel**	8k
VI	**Albion**	2k
VI	**Grayville**	2k
VI	Owensville	1k
V	**Bridgeport**	2k
V	Sumner	1k
V	Lawrenceville	4k
V	Princeton	9k
V	**Fort Branch**	2k
IV	**Springfield**	116k
IV	Indianapolis	773k

bold cities appear on map (k = x1000)

This information was automatically generated and has not been reviewed by a seismologist.

http://earthquake.usgs.gov/pager

Event ID: us2008qza6

Figure 1. *Summary "onePAGER" example for the April, 2008, magnitude 5.2 Illinois earthquake. Elements are event information (top center); the summary alert level (yellow circle, top center); intensity scale with estimated population exposed per intensity level (top center); population exposure map with superimposed color-coded contours of intensity (lower left); impact alert levels for estimated fatalities (top) and economic damages (bottom) with model uncertainty for each range of impact (middle right); selected city list indicating population and color-coded intensity (lower right).*

Alerting: Proposed Activation Levels based on Past Earthquakes

With the advent of the *PAGER* system, domestic (U.S.) and international earthquake responders are reconsidering their automatic alert and activation levels as well as their response procedures. To help facilitate rapid and proportionate earthquake response, we propose alerting based on two complementary criteria. One, based on the estimated cost of damage, is most suitable for domestic events; the other, based on estimated ranges of fatalities, is more appropriate for most global events.

Simple thresholds, derived from the systematic analysis of past earthquake impact and response levels, turn out to be quite effective in communicating predicted impact and response level of an event, characterized by alerts of green (little or no impact), yellow (regional impact and response), orange (national-scale impact and response), and red (major disaster, necessitating national or even international response).

FEMA Activation Alert Levels. Domestically, the Federal Emergency Management Agency (FEMA) and other response agencies and organizations are considering moving beyond magnitude and location-based triggers alone to automatic response activation based on *PAGER*'s near real-time estimates of intensity and population exposure, and damage. FEMA needs to make rapid decisions as to what activation levels are implemented for the National and Region Response Coordination Centers (NRCC and RRCC). Significant forward-looking response planning following the Post-Katrina Emergency Reform Act of 2006 (PKEMRA), entails developing and activating pre-scripted mission assignments and specific earthquake-response actions depending on the initial activation level. FEMA has three response activation levels: Level I (catastrophic impacts), Level II (significant impacts), and Level III (considerable damage) for rapidly activating resources. FEMA's response activities require pre-determined executions to address the first several hours of a major earthquake to expedite assistance. FEMA territories consist of 10 Regions and 3 Divisions (*Figure 2*, East, Central and West); Level I initiates response from resources in the two closest divisions; Level II activates response of all resources in the respective division; Level III triggers resources in the respective region. Activation levels need to be appropriate for different geographic regions since overall earthquake vulnerabilities as well as response capabilities vary from one region to another.

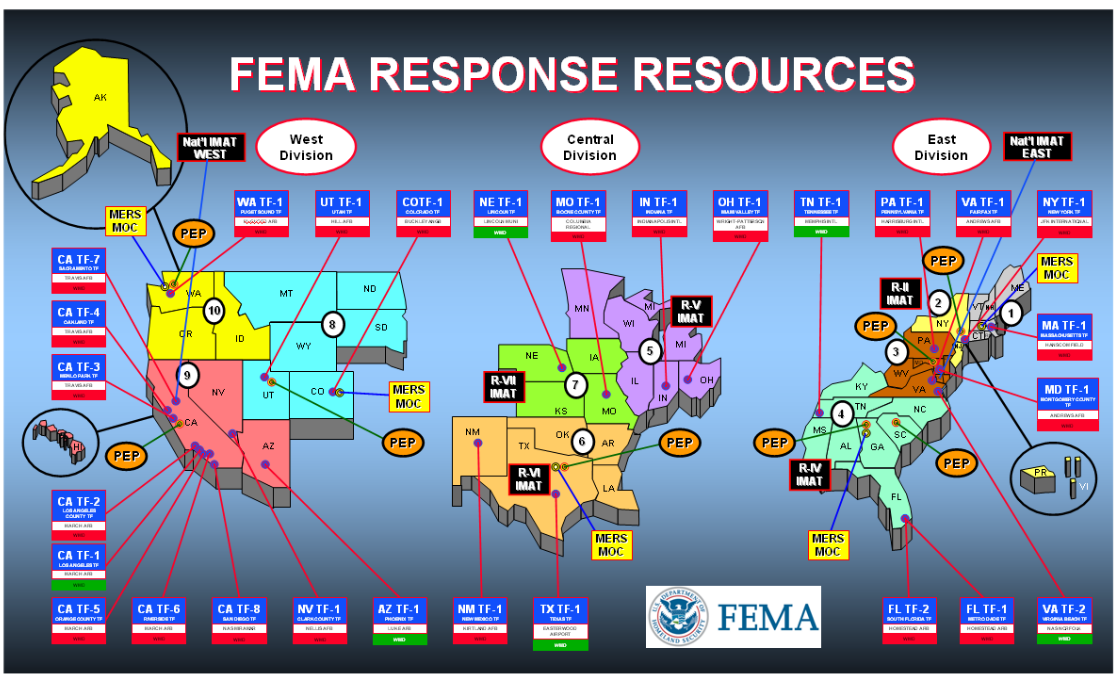


Figure 2. FEMA Response Resources, color-coded FEMA Regions (white-numbered circles), and FEMA Divisions.

We have recently developed recommended alert levels using loss estimates by the *PAGER* system along with dollar-loss thresholds consistent with FEMA's activation levels. Analyses of recent and past earthquakes over the past four decades indicates that alert levels set against overall financial impacts of those events provides a relatively robust criteria for setting the FEMA activation levels. Based on *PAGER* intensity-population exposure estimates for the past 35 years of U.S. earthquakes derived from the ShakeMap Atlas (Allen et al., 2009), and by comparison with actual or estimated damage as well as activation levels implied or implemented for these events, we assigned yellow, orange and red thresholds that are triggered by estimated economic losses reaching $1M, $100M, and $1B, respectively (Table 1; see Wald et al., 2010). In the central and eastern U.S., where actual loss data from recent earthquakes are limited, we supplemented small, recent events with *ShakeMap* scenarios, *PAGER* exposure estimates, and Hazards U.S. (*HAZUS*) damage estimates to determine the appropriate activation levels. These color-coded alerts, their triggering thresholds, and their historic response levels are summarized in *Table 2*.

Earthquake Name	FEMA Alert level	Magnitude	Shaking Deaths	Damage (Millions)
Ungava, Quebec	0	6.3	0	$ [illegible]
Hector Mine, California	0	7.2	0	$ 0
Saguenay, Quebec	0	5.9	0	$ 1
Diamond Bar, California	0	5.4	0	$ 1
Oceanside, California	0	5.8	0	$ 1
Fort Payne, Alabama	3	4.6	0	$ 2
Elmore Ranch, California	3	6	0	$ 4
Superstition Hills, California	3	6.5	0	$ 4
North Palm Springs, California	3	6	0	$ 5
Mount Carmel, Illinois	3	5.2	0	$ 6
Wells, NV	3	6	0	$ 7
Klamath Falls, Oregon	3	6	1	$ 8
Morgan Hill, California	3	6.2	0	$ 8
Au Sable Forks, New York	3	5.1	0	$ 9
Upland, California	3	5.7	0	$ 13
Coalinga, California	3	6.3	0	$ 31
Borah Peak, Idaho	3	6.9	2	$ 33
Sierra Madre, California	3	5.6	1	$ 34
Napa, California	3	5	0	$ 50
Cape Mendocino, California	3	7.2	0	$ 75
Landers, California	3	7.3	1	$ 100
Denali, Alaska	2	7.9	0	$ 150
Magna, UT SCENARIO	2	5.2	0	$ 174
Puget Sound, Washington	2	6.5	7	$ 192
Hebgen Lake, MT	2	7.3	28	$ 193
San Simeon, California	2	6.6	2	$ 200
Unimak Islands, Alaska	2	8	NaN	$ 200
Kiholo Bay, HI	2	6.7	0	$ 270
North Washington, UT SCENARIO	2	6.5	4	$ 386
Kern County, California	2	7.3	12	$ 408
El Centro, CA	2	7.1	9	$ 510
Whittier Narrows, California	2	5.9	8	$ 522
Puget Sound, Washington	2	6.5	8	$ 727
Anderson Junction, UT SCENARIO	1	7.5	84	$ 1,100
Prince William Sound, Alaska	1	9.2	15	$ 1,200
Nisqually, Washington	1	6.8	0	$ 2,000
San Fernando, California	1	6.6	65	$ 2,200
Brigham City, UT SCENARIO	1	7	422	$ 3,700
Western Illinois SCENARIO	1	6	1	$ 4,200
Loma Prieta, California	1	6.9	62	$ 5,600
Ardsley, New York SCENARIO	1	5.1	0	$ 5,941
San Francisco, CA	1	7.9	NaN	$ 8,000
1886 Charleston, SC SCENARIO	1	7.3	900	$ 20,000
Wabash Seismic Zone SCENARIO	1	7.1	237	$ 32,800
Northridge, California	1	6.7	33	$ 40,000
Salt Lake City, UT SCENARIO	1	7	6222	$ 44,000
NMSZ SW Segment SCENARIO	1	7.7	2869	$ 51,800

Level III ~$1M to $100M

Level II ~$100M to $1B

Level I ~>$1B

Table 1. U.S. historic and scenario earthquakes, their corresponding inferred FEMA Alert level, and associated damage in millions of dollars.

Also shown in Table 2, *PAGER* yellow, orange and red alerts based on the Earthquake Impact Scale correspond to FEMA's Level III, II, and I Level alerts, respectively. We anticipate that the *PAGER* alert levels can be used for prescribed response plans like FEMA's, as well as to trigger less formal response activities.

PAGER Alert Level	FEMA Activation Level	Estimated Losses ($M)	Approximate Annual Occurrence
Red	**Level I**	**> 1,000**	0.1 (1 per 10 yrs)
Orange	**Level II**	**100 – 1,000**	0.2 (1 per 5 yrs)
Yellow	**Level III**	**1-100**	0.5 (1 per 2 yrs)
Green	**No Activation**	**< 1**	4.7 per yr

Table 2. *PAGER Alerts, FEMA Activation Levels, associated loss triggers, and the annual occurrence of each trigger level based on the past forty years of earthquakes in the United States.*

Role of FEMA's HAZUS with USGS ShakeMap

HAZUS is short for Hazards U.S. Multi-Hazard or *HAZUS-MH*, a FEMA-developed and GIS-based software system built around sophisticated risk-assessment methodologies designed to estimate potential losses from earthquakes, floods, and hurricane winds. FEMA has continually improved the *HAZUS* earthquake model, issuing a series of upgrades in recent years. The model can now generate various estimates of damage (e.g., casualties, displaced households, outages) and loss (e.g., repair and replacement costs, value of lost wages and building contents) relating to affected populations, to commercial, industrial, and residential structures, and to transportation and utility lifelines.

Scenarios for Mitigation

Realistic earthquake scenarios that describe the ground motions and damaging effects that large earthquakes would likely produce in particular regions, including the ongoing 2011/2012 New Madrid Catastrophic Planning work, have developed into a standard and useful vehicle for planning. It is in this context that ShakeMap, which projected the ground shaking likely in scenario earthquakes, is often used alongside *HAZUS*, which estimated the aggregate scenario losses that were used to measure resource requirements for response, recovery, and loss-mitigation activities.

HAZUS and ShakeMap Post-Earthquake

In an upgrade released in 2005, FEMA calibrated *HAZUS* specifically for ShakeMap input, enabling the system to generate more accurate loss estimations. Rapid *HAZUS* loss modeling incorporating ShakeMap data in future earthquakes will provide more detail on impacts and losses than the current *PAGER* product and be developed in the first few hours following the earthquake. The accuracy of the *HAZUS* loss information for the New Madrid scenarios benefits from the recent data and modeling improvements as a result of the Catastrophic Planning initiative.

Obviously, both FEMA's *HAZUS* and USGS's *PAGER* products perform loss estimations, however, their coordinated development ensured there was no duplication of efforts and there are several fundamental differences between these systems. First, is timeliness: the availability of these products (see Figure 3) is generally under 20 minutes for *ENS, ShakeMap, and PAGER*; initial *HAZUS* results after 2 hours followed by a *HAZUS/ShakeMap* ground-truthing process that takes place during the next 48 hours or more. The methodology behind the *PAGER* system is quite different than *HAZUS* and consists primarily of empirical models based on losses from past earthquakes. Future releases of the *PAGER* system will incorporate *HAZUS* methodologies where applicable. However, as a primarily empirical model, *PAGER* is more limited than *HAZUS* in terms of the loss information modeled. *HAZUS* results include more details on economic losses and social impacts that not only support the response activities, but also post-earthquake recovery and mitigation *(Table 3).*

Another fundamental difference is the availability of results, *PAGER* results are publically available: alerts are provided via cell, pager, and email; openly-accessible web pages provide more *PAGER* details and thus results are widely available for the public, media, aid agencies and responders. Conversely, although *HAZUS* software is publically available, official results post-event are often restricted and at DHS are governed by a Geospatial Concept of Operations (GeoCONOPS).

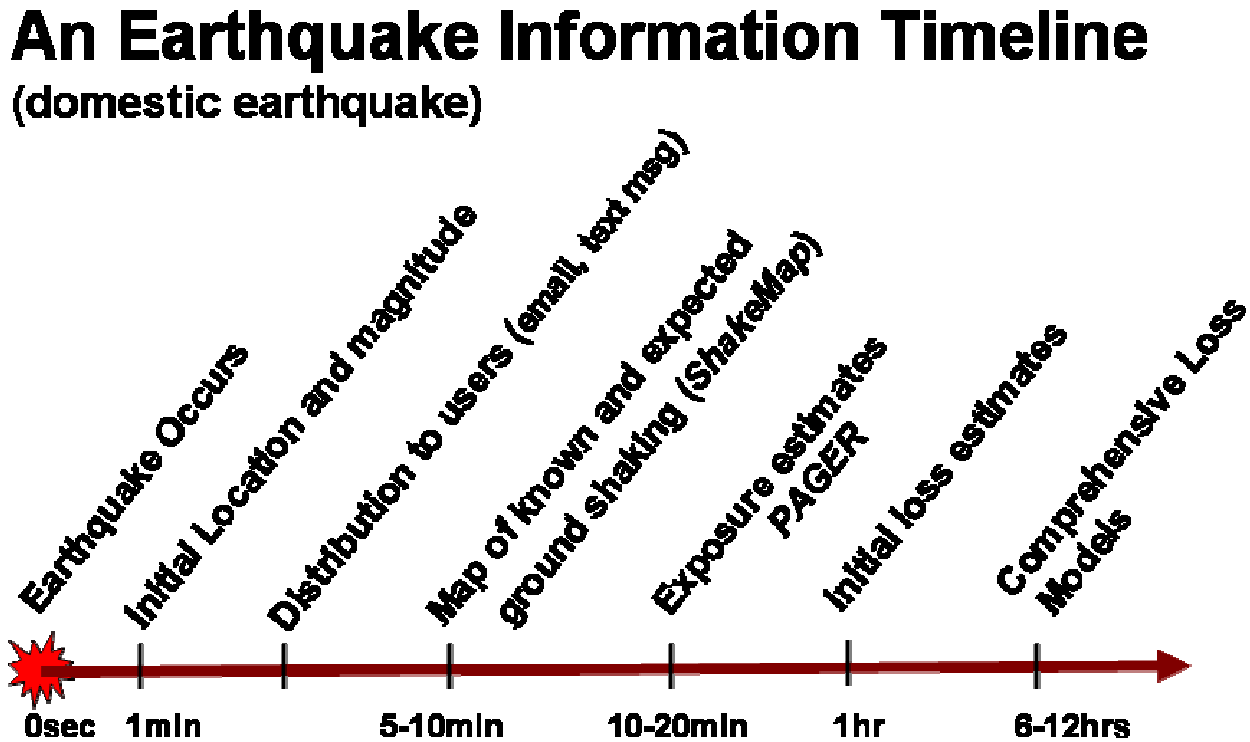


Figure 3. General timeline of post-earthquake product availability. Exact timeliness depends on a number of event-specific factors, for example location and magnitude are determined more rapidly in California than other parts of the U.S.

Purpose	Earthquake Notification	Shaking Distribution	Population Exposure	Loss Estimation
Response	*ENS, ShakeMap, ShakeCast, PAGER*	*ShakeMap*	*ShakeMap/ PAGER*	*ShakeMap/ShakeCast, ShakeMap/PAGER, ShakeMap/HAZUS*
Planning & Mitigation	—	Probabilistic Hazard Maps, Scenario *ShakeMaps*	*ShakeMap/PAGER ShakeMap/HAZUS*	*ShakeMap/HAZUS*

Table 3. *Products and tools associated with planning versus Response. Green colored text denotes products are available within 10-20 minutes of an earthquake; red color products are typically available within several hours of an event. A "/"separates input/output for integrated products, respectively.*

Conclusions

For the time being, responders who currently make decisions based on magnitude and location may prefer to continue to use magnitude as a primary notification and initial "heads up" on earthquake occurrence. For these purposes, *ENS* should be the primary, preliminary tool. However, we expect that the continued evolution content-rich geospatial information like *ShakeMap*, *ShakeCast*, *PAGER* and FEMA's *HAZUS* will enhance users expectations for additional content in order to improve their post-earthquake situational awareness and decision-making. *PAGER*-based alert thresholds proposed based on economic impact, combined with *ShakeMap*, *ShakeCast*, *PAGER* and FEMA's HAZUS maps can provide additional and more informed initial criteria for rapidly activating appropriate levels of response and for focusing activities in the most needed areas. In summary, *PAGER* is for initial situational awareness and alerting; *HAZUS* is more suitable for longer-term mitigation as well as response management and recovery.

References

Allen, T.I., Wald, D. J., Earle, P. S., Marano, K. D., A. J. Hotovec, Lin, K, and Hearne, M. G. (2009). An Atlas of ShakeMaps and population exposure catalog for earthquake loss modeling, *Bull. Earthq. Eng., v. 7.*

Jaiswal, K.S., Wald, D.J., and Hearne, M., (2009). Estimating casualties for large earthquakes worldwide using an empirical approach: U.*S Geological Survey Open-File Report*, OF 2009-1136, 78 p.

Wald, D. J., K. Jaiswal, K. Marano, K. D., and Bausch, D. (2010). An Earthquake Impact Scale, submitted to *Natural Hazards Review*.

Wald, D. J., Lin, K., Porter, K., and Turner, L. (2008a). ShakeCast: Automating and Improving the Use of ShakeMap for Post-Earthquake Decision-Making and Response, *Earthquake Spectra*, 24:2, 533-553.

Wald, D.J., Earle, P.S., Allen, T.I., Jaiswal, K., Porter, K., and Hearne, M. (2008b), Development of the U.S. Geological Survey's PAGER System (Prompt Assessment of Global Earthquakes for Response), Proceedings of the 14th World Conf. on Eq. Engineering, Beijing, China, 8 pp.