DEVELOPING METHODOLOGIES FOR RAPIDLY UPDATING PAGER LOSS ESTIMATES

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OUTLINE

- Brief history of PAGER...
- How PAGER loss modeling works?
- How PAGER has performed over the years?
- Challenges & motivation of current research
- Bayesian updating framework
- Results & Discussion
Development timelines...

- The USGS Golden team (David Wald and Paul Earle) hosted a workshop in April 2004.
- PAGER developments formally started at the USGS in 2006 after the Presidential funding support received following to December 26, 2004 Sumatra Indonesia earthquake.
PAGER: OVERVIEW

- Automated system operational since Sept 2010, at NEIC of USGS in Golden Colorado
- Rapidly estimates earthquake shaking-related impacts in terms of deaths and direct economic impact before the ‘ground-truth’ data becomes available
- Based on data and models that are open and publicly available
- Functionality goes beyond rapid estimations, such as scenario building for pre-earthquake mitigation planning

Estimated Fatalities

- Estimated Economic Losses

Estimated Population Exposed to Earthquake Shaking

- Population Exposure

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Event ID: nc72282711
PAGER LOSS MODELING FRAMEWORK

PAGER ELEMENTS

LOSS ESTIMATION

- Population Exposure (by Cell & per Ground Motion)
- Building Inventory
- Analytical Loss Model (Spectral Accel.)
- Time of Day, Urban Rural, Work Force, Countries
- Fatality Estimates
- Semi-Empirical Loss Model (Intensity)
- Expert Building Vulnerability
- Empirical Loss Model (Intensity)
- Country Vulnerability
PAGER’S FATALITY MODELING APPROACH

\[ \nu(S_j) = \Phi \left( \frac{1}{\beta} \ln \left( \frac{S_j}{\theta} \right) \right) \]

Nearly four orders of magnitude difference in fatality rates

Fatality rates are very small at this level of shaking

Plot showing typical variation in the fatality rates among the selected earthquake-prone countries
EARTHQUAKE IMPACT ESTIMATE

**Estimated Fatalities**

- None
- Regional
- National
- International

**Estimated Economic Losses**

- $1M
- $100M
- $1B
- $100B

**Damage**

\[ P(a < d \leq b) = \Phi \left[ \frac{1 - b \phi - 1}{\xi} g e \right] - \Phi \left[ \frac{a \phi - 1}{\xi} g e \right] \]
HOW OFTEN DO WE GET G/Y/O/R ALERTS?

Time Window: September 22, 2010 through March 31, 2019
NEIC has registered ~12,000 earthquakes (M>5.0) worldwide

18 Red alerts (1000+ deaths, 1.0 B$ ) 40 Orange alerts (100+ deaths, 100 M$)
175 Yellow alerts (1+deaths, 1 M$) & 4,903 Green alerts*.
PAGER results for selected versions of the August 24, 2014 Napa, CA earthquake.

<table>
<thead>
<tr>
<th>PAGER Version Number</th>
<th>Summary Alert Level</th>
<th>Estimated impact in terms of Fatalities</th>
<th>Estimated impact in terms of economic loss</th>
<th>Reason(s) for alert change</th>
<th>PAGER alert creation time after earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yellow</td>
<td>person killed and 200 injured</td>
<td>$362 million- $1 billion</td>
<td>N/A</td>
<td>13 min.</td>
</tr>
<tr>
<td>2</td>
<td>Orange</td>
<td></td>
<td></td>
<td>EQ mag. increased from M5.7 to M6.0</td>
<td>19 min.</td>
</tr>
<tr>
<td>13</td>
<td>Red</td>
<td></td>
<td></td>
<td>Addition of station near epicenter</td>
<td>~6 hours</td>
</tr>
<tr>
<td>22</td>
<td>Orange</td>
<td></td>
<td></td>
<td>Corrected bias calculation</td>
<td>~34 hours</td>
</tr>
<tr>
<td>24</td>
<td>Red</td>
<td></td>
<td></td>
<td>Addition of more station data</td>
<td>~42 hours</td>
</tr>
</tbody>
</table>

PAGER estimates do change over time as new shaking data/constraints gets incorporated.
PAGER’S ALERTING ACCURACY

Estimated Fatalities - Final PAGER Version
September 2010 - December 2018
PAGER’S ALERTING ACCURACY

Estimated Economic Losses - Final PAGER Version
September 2010 - December 2018

Predicted Losses (Million USD) vs. Reported Losses (Million USD)
MOTIVATION:

- Suppose that PAGER significantly under/over-estimates the loss for a given earthquake

- Questions:
  - Can reported damage/losses be used to improve PAGER estimate?
  - Can we improve PAGER’s initial estimates within 24~48 hrs?
HOW LOSSES GET REPORTED?

Death toll in Nepal from 25th April 2015 Quake (8471 dead & 237 missing) & from 12th May 2015 Quake (153 dead) (built from Nepal Police and NEOC death toll counts in CATDAT)

2015 Mw 7.8 Gorkha, Nepal Earthquake

Earthquake-Report.com
FITTING REPORTED LOSS DATA WITH THE EXPONENTIAL CDF MODEL

Loss data gathered from Zhao et al., 2008

Loss at time $t$ is given as: $X(t) = N_\infty (1 - e^{-\alpha t})$
ESTIMATING THE PROJECTION RATE $\alpha$

- 19 past earthquakes were used to estimate $\alpha$ for any given earthquake.

- Values of $\alpha$ for each of these earthquakes are found using nonlinear regression on the reported loss model.

- We then seek a relationship between $\alpha$ and the maximum shaking* for each event.
RELATIONSHIP BETWEEN LOSS PROJECTION RATE, AND MAXIMUM SHAKING @ 10,000 PEOPLE EXPOSED

Log(α) vs. Max MMI

Linear Relationship:

\[ \log(\alpha) = -0.634 \times \text{MMI}_{\text{Max}} + 5.545 \]

residual std = 0.414
• Step 0: (Initial State)
  • Estimate prior information \( f_{N_\infty}(n_\infty) \) and projection rate \( \alpha \)

• Step 1: (First Reported Loss)
  • Collect first reported loss \( x(t_1) \) at time \( t_1 \) with estimated uncertainty

• Step 2: (Loss Projection)
  • Transform reported loss \( X(t_1) \) to an observation of total loss \( X_\infty(t_1) \) using projection model:
    \[
    X_\infty(t_1) = \frac{X(t_1)}{1 - e^{-\alpha t}}
    \]

• Step 3: (Bayes Update)
  • Update prior PAGER estimation using the Bayes equation:
    \[
    \frac{f_{N_\infty}(n_\infty|x(t_1))}{1/C \cdot f_{N_\infty}(x(t_1)|n_\infty) f_{N_\infty}(n_\infty)}
    \]
  • Repeat steps 1-3 for next reported loss \( x(t_2) \) at time \( t_2 \)
The diagram illustrates a loss projection model with the following key components:

- **Initial Loss Density (Prior)**: This represents the initial estimate of losses before any data update.
- **Posterior Update (\(N_x|X_t\))**: This indicates the updated estimate of losses after incorporating new data at time \(t=\text{2 hours} \Rightarrow X_{t=\text{2 hours}}\).
- **Data Likelihood (\(X_x|t=\text{2 hours}\))**: This shows the likelihood of the data given the model at the specified time.

**Fatalities** vs. **Time (Days)**

- The x-axis represents time in days, ranging from 0 to 8.
- The y-axis represents fatalities, ranging from 0 to 1,000,000.

Additional notes:

- All densities are scaled for clarity.
- The right side of the diagram includes a PAGER histogram for time \(t=\text{2 Hours}\), showing specific percentages and data points.
2015 MW 7.8 GORKHA, NEPAL EARTHQUAKE

- April 25, 2015
- 8471 Reported Deaths
- 21,952 Injured
- 3.5 Million Homeless
- Est. $10 Billion in damages

Suppose PAGER exactly estimated the final reported loss.
The median updated total loss over time is plotted along with its uncertainty.
Initial PAGER Estimate: Final Obs /100

- $t = \sim 20$ min.
- $t = 7$ Hours
- $t = 29$ Hours
- $t_{\text{final}} = 28$ Days

Evolution of the PAGER Loss Histogram Over Time
• Incorporate region-specific projection rate $\alpha$

• Explore different loss-projection models

• PAGER model improvement, re-calibration incorporating ShakeMap uncertainties
ORIGINAL SHAKEMAP WITH SAMPLE GROUND MOTION RANDOM FIELD REALIZATIONS FOR 2015 MW 7.3 GORKHA EARTHQUAKE
MODEL CALIBRATION INCORPORATING SHAKING UNCERTAINTY

Reported Total Deaths vs. PAGER Estimated Deaths for Major Past Earthquakes in China from 1973-2008 Original fatality rate model (left), New fatality rate model (right) including shaking uncertainty
IMPLEMENTATION CHALLENGES

- Authoritiveness of the reported loss data
- Whether the update changes the PAGER alert significantly to re-send notifications to OFDA
- Issues with low fatality earthquakes (0-100)?
- Timeliness??
THANK YOU FOR YOUR ATTENTION...!

QUESTIONS/COMMENTS?

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