Seismic risk assessment of complex transportation networks

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Los Angeles suffered from 1994 Northridge earthquake

56% of closed businesses cited employees’ inability to get to work (Tierney 1997)

Image source: Caltrans (Zelinski 1994)
The San Francisco Bay Area is seismically active
Many key transportation lines trace major faults
Prior work lays foundation for measuring this risk

- **Analytical methods**
  - Capture rare events efficiently (e.g., Lee et al. 2007)
- **Scenario-based assessment**
  - Often larger network sizes (e.g., Rokneddin et al. 2013, Kiremidjian et al. 2007)
  - Miss range of possibilities
- **Event-based assessment**
  - Capture risk probabilistically (e.g., Jayaram 2011)
  - Often a disconnect between topology-based methods and decision-maker needs
  - Computational costs tend to lead to small networks (e.g., Hernandez-Fajardo and Dueñas-Osorio 2011)
Scenario-based assessments have shortcomings
Scenario-based assessments have shortcomings

Image source: BART Seismic Safety Team
Key points of today’s talk

1. Proposed framework enables modeling both for a wide range of events and in depth to understand impacts at a local level

2. Accessibility losses are predicted to vary greatly from community to community here in the Bay Area

3. Communities with higher walkability and bike-friendliness will likely be less impacted by losses in accessibility
Benefits

Researcher

Transportation Planner

Resident (you!)
Step 1: Earthquake scenario and ground-motion intensity map

- Seismic source model
- Site conditions
- Spatial correlation model
- Ground motion prediction equation
Step 1 continued: Seismic source model captures uncertainty in magnitude and location

- Hundreds of sources
- Discretized by rupture location and magnitude
- Result is thousands of scenarios
- Each scenario with annual likelihood
Step 2: Damage map

- Fragility functions link shaking to damage
- 1743 road components (some of which may impact transit lines)
- 3152 BART components
- Data current as of 2012
Step 2 continued: Sample fragility curve

Probability of being damaged

Ground shaking intensity

University Avenue & El Camino
Real bridge
Step 3: Damaged network and network performance

- Road and transit networks
- Traffic model
- Trip demand information
- Functional percentage relationships
- Network-component matching
- Network interdependencies
Step 3 continued: High-fidelity travel model enables detailed investigation of impacts

- **Variable travel demand**
- 11,921 road nodes
- 32,858 road edges
- Cars, **rail, ferry, buses**
- 1% of the population as agents with trip preferences
- 6+ hours to analyze network and behavior
Step 3 continued: Efficient travel model

- 11,921 road nodes
- 32,858 road edges
- Cars only
- First application of iterative traffic assignment method (Chen and Alfa 1991) to seismic risk assessment
- **Quick**: 20-35 seconds per damaged network in series, < 0.5 seconds in my distributed framework
Step 4: Measuring the impacts on people

- Mode preferences
- Destination preferences
- Household data
Sample event

Step 1: Ground-motion intensity map

Step 2: Damage map

Step 3: Damaged network and network performance

Step 4: Performance measure
Loss exceedance curve from event set

Performance measure
Map subset selection using optimization

Performance measure
Next step is to more closely link transportation damage to the impact on people and communities

How easily can I get to where I want to go today—one week after “the big one”?
Mode-destination accessibility definition

A measure of how easily a person can travel where he or she wants to go (Niemeier 1997)

\[ Acc_a = \ln \left[ \sum_{\forall \in C_a} \exp(V_a(c)) \right] \]

Accessibility of the \( a^{th} \) agent  
Set of choices for the \( a^{th} \) agent  
Utility for the \( a^{th} \) agent for the \( c^{th} \) choice
Accessibility covers mode and destination choices

Caltrain to Stanford?
Work from home?
Get groceries instead?
Accessibility loss varies greatly across region
3 case study communities

Expected decrease in accessibility
Annual rates of losses vary greatly.
1. Trip length not a strong predictor
2. Income class not a key risk factor

![Graph showing annual exceedance rate (\(\lambda\)) against decrease in accessibility (\(X\)) for different income classes: Low, Medium, High, and Very high. The graph indicates that income class is not a key risk factor in terms of accessibility.

- **Low income**
- **Medium income**
- **High income**
- **Very high income**
3. Taking local trips by foot linked to reduced risk
4. Difference in redundant roads

Accessibility losses

Map of roads
5. Transit functionality plays a key role in impact.
Multiple factors related to accessibility

1. Income class

2. Average trip distance

1. Baseline percentages of trips by foot

2. Network topology

3. Transit network interactions
Future work

- Changes of risk over time
- Other sources of damage and failure modes
- Models of post-earthquake traffic based on sensor data
- Use of sensors and social media for rapid, post-earthquake transportation network evaluation
Future work (continued)

Tweets Can Guide Emergency Responders Almost Immediately After An Earthquake tcrn.ch/1joxzWN
by @catherineshu
10:30 AM - 2 May 2014

Tweets Can Guide Emergency Responders Almost Immediately After An...

Aggregated data from sites like Google and Twitter have given researchers new ways to track things ranging from diseases to emergency responses after a disaster. Now Stanford researchers are using…

TechCrunch @TechCrunch

72 RETWEETS 38 FAVORITES
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Image source: George Nikitin, Associated Press
Questions?

Strategies for tractable simulation

Identifying at-risk communities

Variations in risk between communities

Walkability lowers risk

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