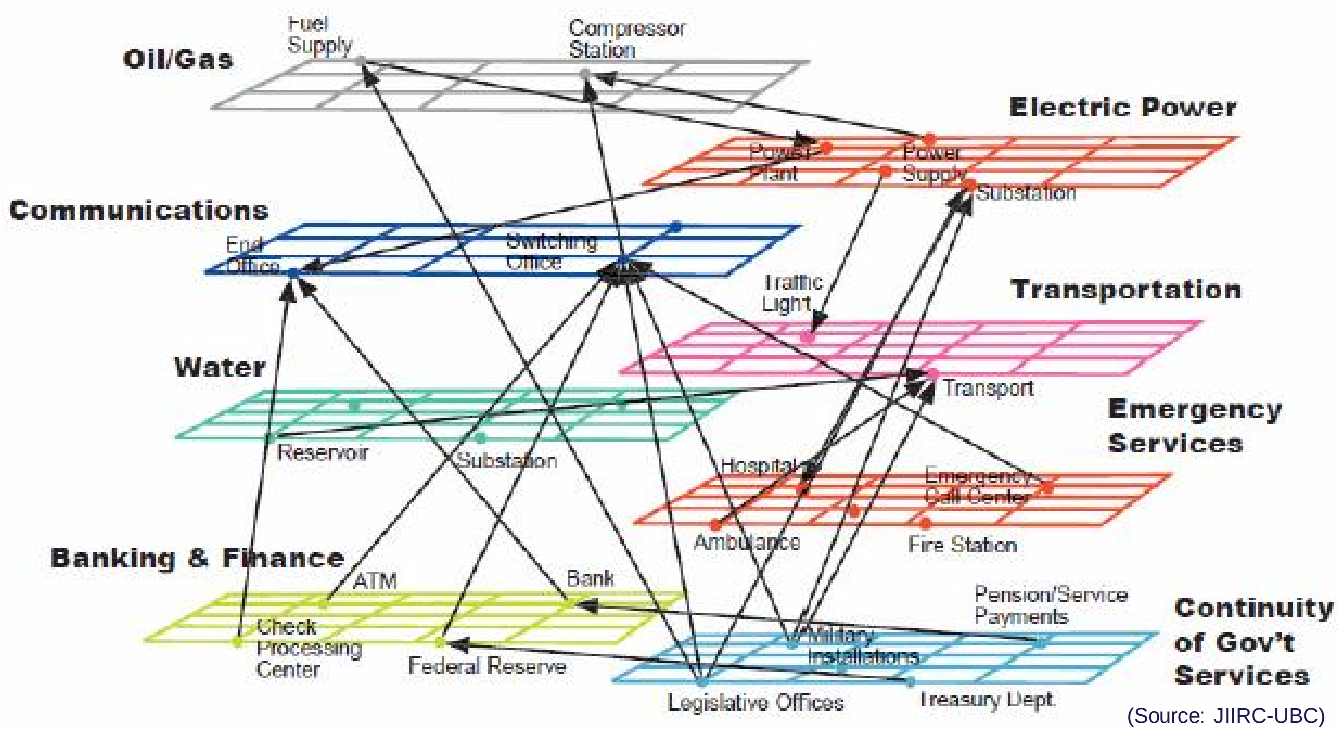
Scoping the Lifelines Council's Interdependency Study



(Source: JIIRC-UBC)

Lifelines Council Meeting #5
April 21, 2011

Lifelines Council's Objectives

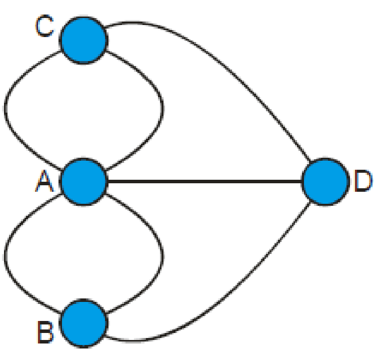
- Develop and improve collaboration in the City and across the region by regularly convening a group of Executive Officers and Senior-level operational deputies of local and regional lifelines providers
- Understand inter-system dependencies to enhance planning, restoration and reconstruction.
- Share information about recovery plans, projects and priorities.
- Establish coordination processes for lifeline restoration and recovery following a major disaster event.

Key Questions to be Answered Before Undertaking Study

- Study purpose/objectives?
  - *Mitigation (risk-consistent design and performance standards, prioritize retrofits)*
  - *Response and restoration planning and/or coordination (e.g. access and permits, single or multi-system dependency/restoration, prioritizing restoration)*
  - *Post-disaster restoration and reconstruction activities*
- Study scope/participants? *All or key lifelines, entire systems or simplified networks and/or assets, city emergency management, other emergency facility operators, community needs*
- Study methods/approach? *Methodology, key interdependencies, inputs/network data, scenarios, analytical tools, technical expertise, outputs, uncertainty*
- Other considerations/constraints? *Data proprietary and security issues, complexity, personnel, technology, funds, timeline*

Seven Bridges of Konigsberg Problem (Leonhard Euler, 1736)

- First rigorous treatment of network problems
- Challenge: find a route around the city of Königsberg that would require a person to cross each of 7 bridges exactly once
- Approach: Lumped land into nodes (vertices) and replaced the bridges with links (edges), obtaining a graph with four nodes and seven links.

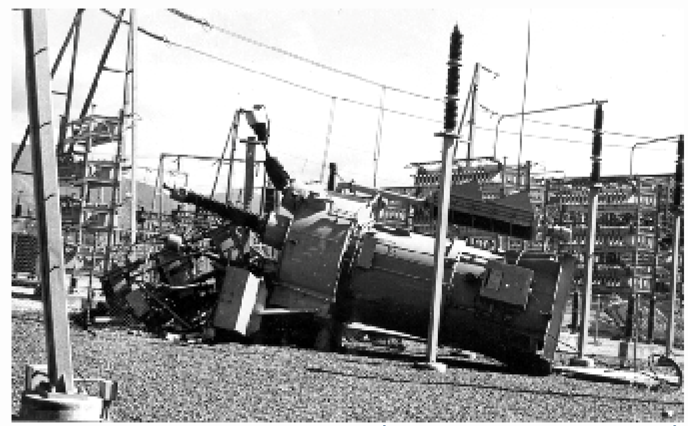


- Proved: There is no solution. A route crossing each link only once does not exist.

(Source: Duenos-Osorio, 2005, p.11)

M6.6 San Fernando Earthquake (1971)

- Significant damage to all lifeline systems—electrical substations, telephone switching office, water and gas distribution systems, major dam, freeway overcrossings, and hospitals
- Lifeline engineering professionals set 30-year goal to “establish a comprehensive set of standards of lifeline performance in earthquakes” that has been “proved out in future earthquakes.”
  - Start of a long-term research program to study the effects of earthquakes on all lifeline systems, and set standards for lifeline seismic design, construction and performance.



(Source: www.usgs.gov)

Oakland/Berkeley Hills Fires (1991)

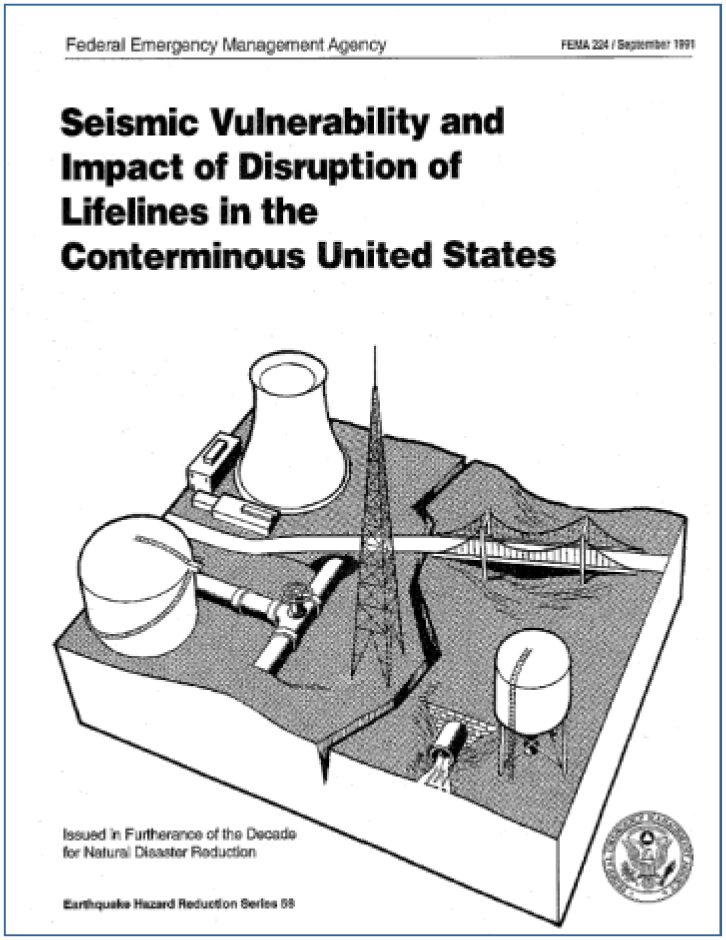
- Inability to supply power to water distribution systems during fires
- 1995 requirement that all municipal agencies in California, including lifeline operators, develop standardized emergency response plans (SEMS, based on ICS and predecessor to NIMS)

(Source: richliebermanreport.blogspot.com)

(Source: ChrisHardyPhotostream, flickr.com)

First Nationwide Study of Seismic Vulnerability of Lifelines

(Scawthorn et al, 1991)


Federal Emergency Management Agency

FEMA 224 / September 1991

Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States

Issued in Furtherance of the Decade for Natural Disaster Reduction

Earthquake Hazard Reduction Series 58

- Construction of a national lifelines inventory
- Development of lifeline vulnerability functions, describing earthquake performance characteristics as well as restoration times
- Characterized seismic hazard of a series of representative earthquakes for most regions of the U.S.; San Francisco used a slightly larger earthquake
- Estimated both direct and indirect economic losses
- Provided a relative ranking of critical infrastructure systems, given estimated losses: 1) electricity; 2) highways; 3) water systems; 4) ports; 5) crude oil

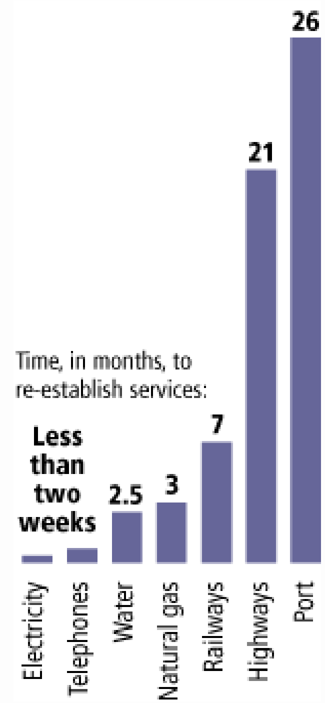
1980's – 1990's: U.S. and Japan collaboration to study lifeline system interaction

M7.1 Loma Prieta(1989) and M6.7 Northridge (1994) earthquakes

- Damages across most lifelines systems, confirming observations from previous disasters
- Many interdependencies observed and documented, particularly electric power and water supplies, and the impacts of their disruption on other lifelines, and fire-fighting
- Large secondary losses from lifeline disruption were not observed
  - Lifeline damages from 2001 World Trade Center and 2005 Hurricane Katrina caused large secondary losses

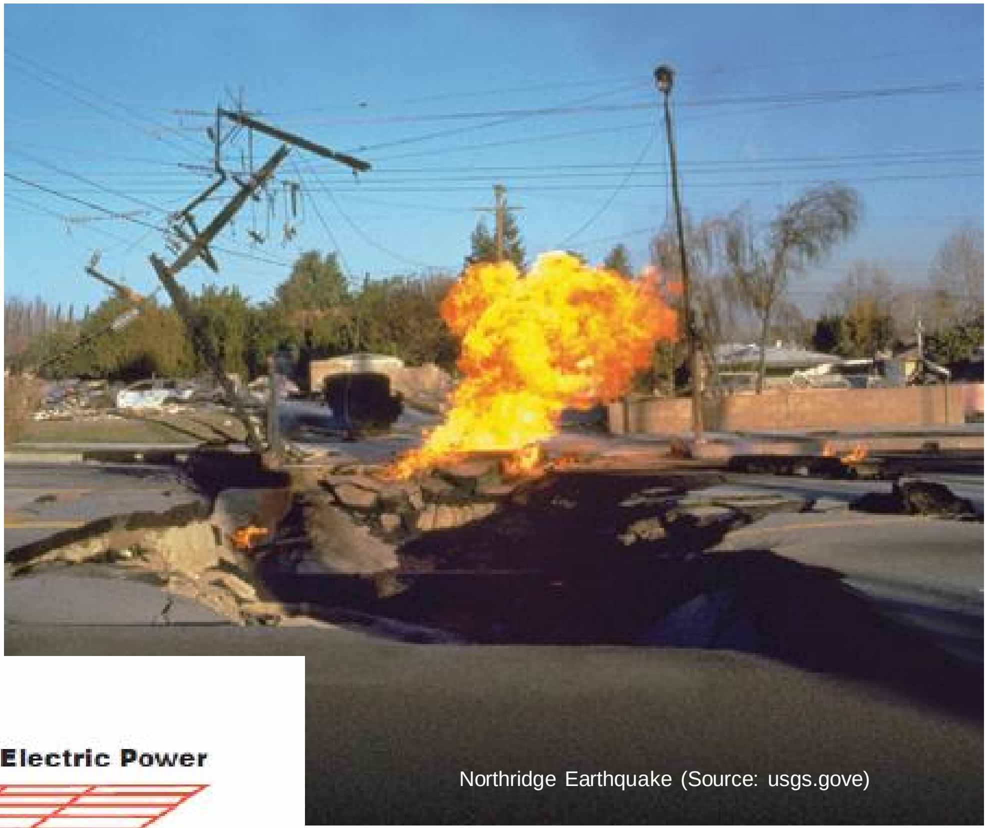
M6.9 Kobe Earthquake (1995)

- Damage across most systems; electric power damage led to multiple infrastructure failures
- Electric power and telecom restored within weeks; water and gas systems took 2 to 3 months; and railways, highways, and port took many months to years
- Illustrated that economic losses of multiple lifeline disruption can equal or exceed repair costs

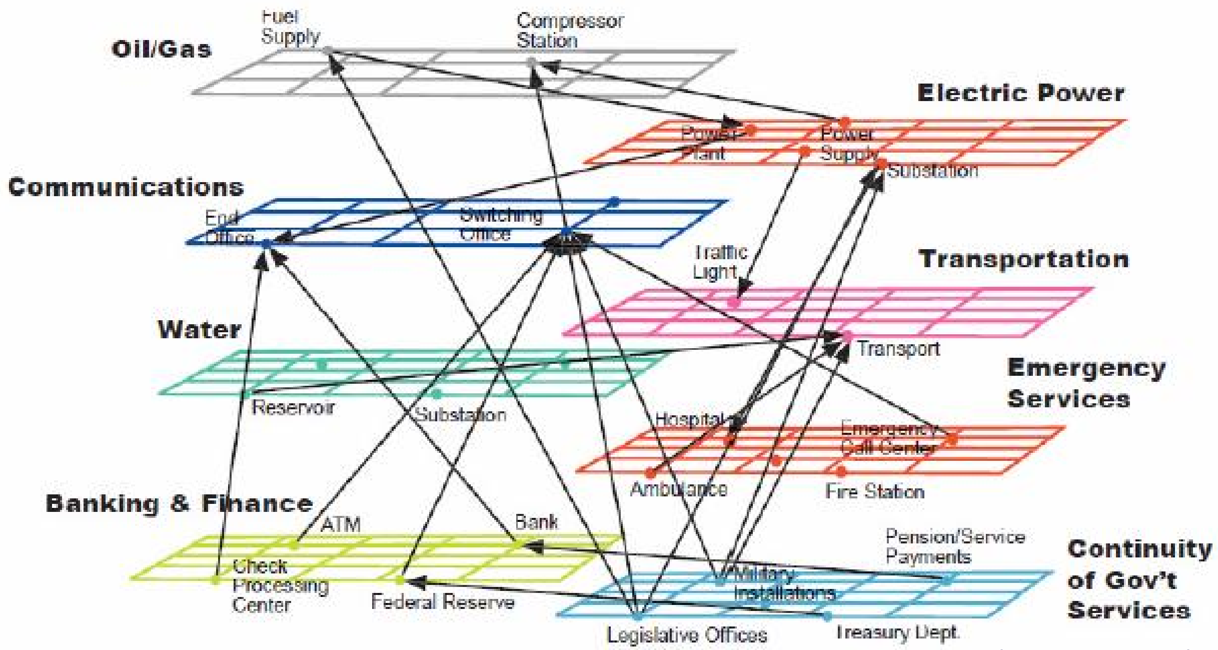


(Source: City of Kobe, 2005)

Infrastructure Interdependencies



Northridge Earthquake (Source: usgs.gove)



(Source: JIIRC-UBC)

Interactions among Lifeline Systems in Earthquakes

(Source: Kameda, Nojima, 1992)

	Electric power supply	Gas supply	Water supply	Transportation	Communication
Electric power supply	*	○ Malfunction of plants, gas holders, pressure devices; ○ Malfunction of centralized control system; ○ No illumination	○ Malfunction of filtration plants & pumping engines; ○ Malfunction of centralized control system; ○ No illumination	○ Traffic signal disorder; ○ Malfunction of electric car & urban railways; ○ Malfunction of centralized control system; ○ No illumination	○ Malfunction of tel. offices; ○ Malfunction of centralized control system; ○ No illumination; ○ Malfunction of online service; ○ Loss of data
Gas supply	□ Excessive use as alternatives, *e.g.* Hot supply	*	△ Recovery work complications; △ Scramble for machinery	○ No passing owing to repair work	
Water Supply	○ Lack of coolant for independent power plants; ● Inundation of underground pipes and cables	△ Recovery work complications; △ Scramble for machinery; ○ Lack of coolant; ○ Lack of coolant for independent power plants	*	○ No passing owing to repair work; ○ Lack of coolant for independent power plants; ● Flooding	○ Lack of coolant for switchboard; ● Inundation of underground cables; ● No insulation; ○ Lack of coolant for independent power plants
Transportation	△ Battery cars unavailable; △ Delay in recovery work; ○No commuting; ○ No transportation of materials and fuel	△ Delay in recovery work; ○ No commuting; ○ No transportation of materials and fuel	△ Water wagons unavailable; △ Delay in recovery work; ○ No commuting; ○ No transportation of materials and fuel	*	□ Telephone excessive use
Communication	○ Malfunction of centralized control system; △ No communication for recovery work	○ Malfunction of centralized control system; △ No communication for recovery work	○ Malfunction of centralized control system; △ No communication for recovery work	○ No passing owing to repair work; ○ Malfunction of centralized control system; △ No communication for recovery work	*

m Functional disaster propagation due to interdependence

△ Interaction hinders recovery

l Physical disaster propagation

Influences on alternative systems

* Influence on same systems

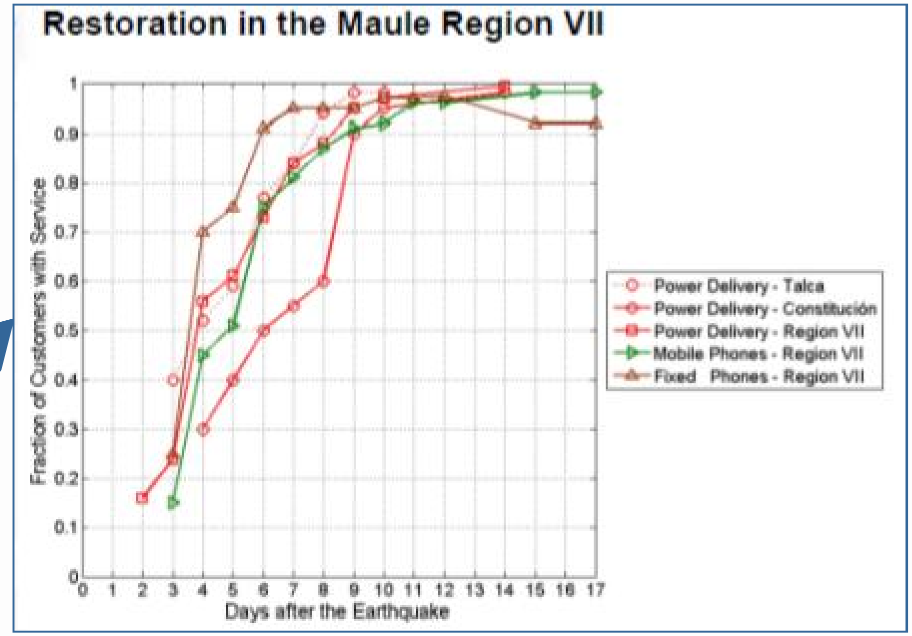
Interactions among Lifeline Systems in Earthquakes

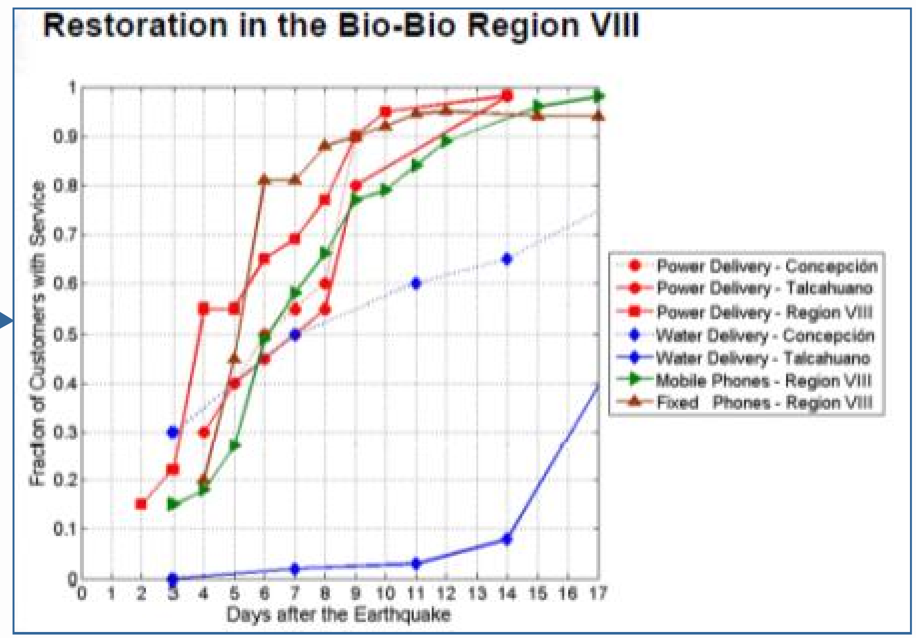
(Yao et al 2005, based on Kameda, Nojima, 1992; Scawthorn 1993; and others)

- Type A – Functional disaster propagation, due to failure of interdependence among lifelines
  - Example: Malfunction of electric power reduces serviceability of water supply system in the same area
- Type B – Collocation interaction, physical disaster propagation among lifeline systems
  - Example: Bridge collapse also disrupts telecommunication cables fixed on the bridge
  - Example: Water from a broken water pipe degrades the transmission performance of telecommunications fiber-optics in proximity to the water pipe
- Type C – Substitute interaction, influences on alternative systems
  - Example: Gas system failure results in excessive requirements for power systems
- Type D – Restoration interaction, various hindrances in the restoration stage
  - Example: system interference in recovery/reconstruction of buried lifelines (e.g. water-gas, power-water, sewer-water)
- Type E – Cascade interaction, increasing impacts on a lifeline due to initial inadequacies
  - Example: Increasing degradation of water service in a conflagration as structures collapse and break service connections, reducing system pressure and water supply for fire-fighting
- Type F – General interaction, between internal components of a lifeline system
  - Example: Connected electrical substation equipment

M8.8 Maule Chile Earthquake (2010)

(Source: Duenos-Osorio, 2011)





M8.8 Maule Chile Earthquake (2010)

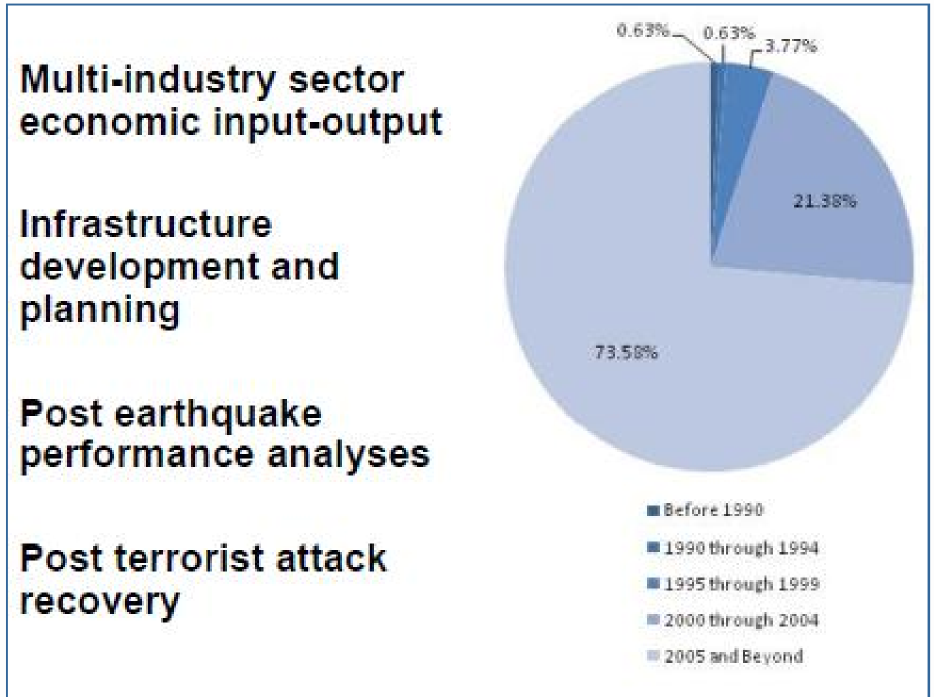
Lifeline interdependencies increased loss of functionality and delayed restoration efforts

- Type A. Functional disaster propagation
  - Electric power damage impacted mobile telecommunication, due to inadequate emergency power, and water system functionality in the undamaged portions of the system
- Type B. Collocation interaction
  - Highway bridge damage impacted collocated telecommunication, gas, and water systems
  - Damaged electric power and/or telecommunication poles halted electric trains
  - Building damage/demolitions impacted rooftop telecommunication and power distribution lines
- Type D. Restoration interaction
  - Water system restoration delays due to refinery damage, fuel shortages, and roadway damage
  - Lack of telecommunications led to delays in damage/safety inspections of electric power distribution, and deployment of crews to repair the water system
- Type E. Cascading interaction
  - Damage at electric power transmission (and sub-transmission) level led impacted undamaged portions of power distribution system

(Source: Modified ASCE TCLEE Chile web report, May 2010; www.eeri.org)

Emerging Field of Interdependent System Modeling Techniques

- Most (~75%) of the interdependency modeling literature is very recent (since 2005)
  - Input-output models
  - Agent-based models
  - Probabilistic network-based approaches
  - Time series analyses
  - Empirical data-based formulations
- Still challenges remain:
  - Unclear how to relate one to another, whether they are complementary or competing
  - Inability to fully integrate institutional, economic, and environmental forces into existing physical models of interdependence



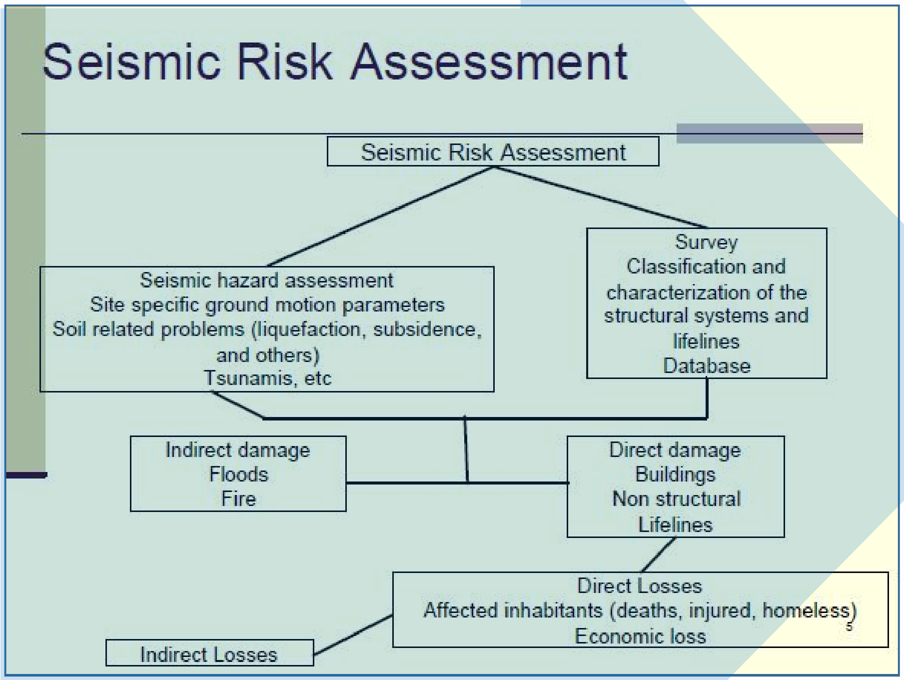
(Source: Duenos-Osorio, 2011)

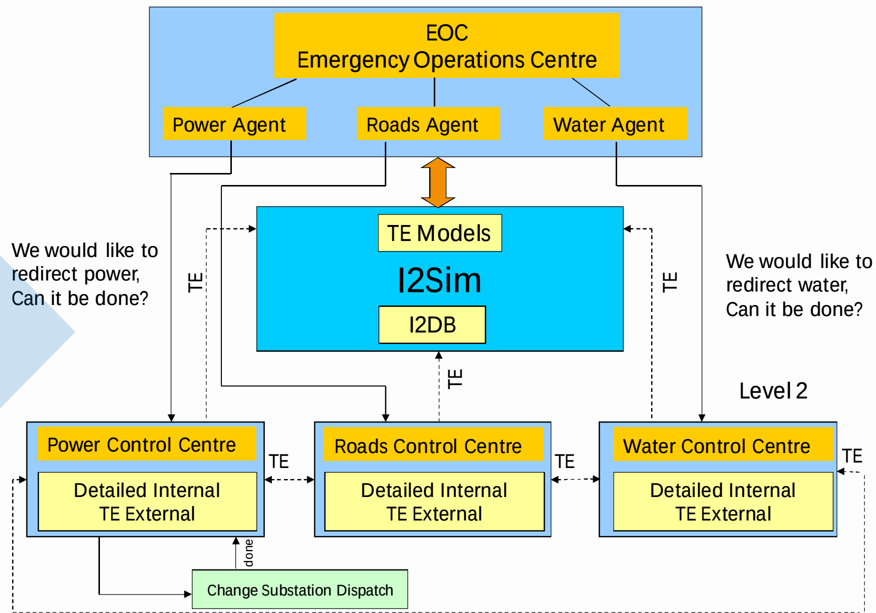
Two Example Study Approaches

	JIIRP – UBC (Marti, Ventura, et al)	**AIDRC – UBC (McDaniels, Chang, Reed, et al)**
Data	Engineering	Empirical observation, Experts
Focus	Systems	Systems
Context	Single event (simulation)	Single event (scenario)
Emphasis	Engineering	Societal impacts
Outcome	Simulation tool	Scenario ranked strategies
Purpose	Emergency Response	Mitigation and preparedness

Joint Infrastructure Interdependencies Research Project (JIIRP)

(UBC - Marti, Ventura, et al)



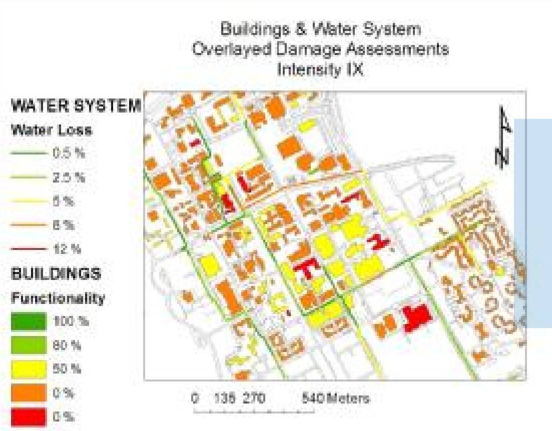


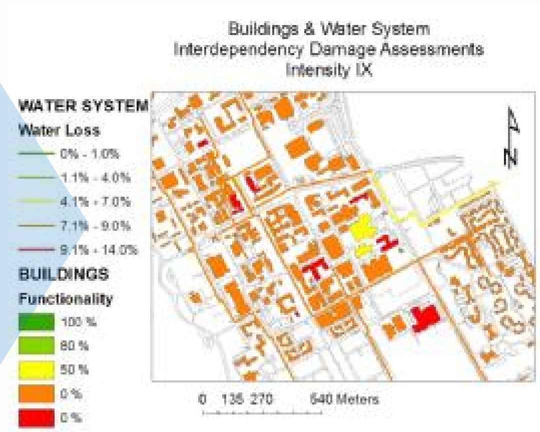
I2Sim Infrastructures Coordination and Control (C2') Environment

Joint Infrastructure Interdependencies Research Project (JIIRP) – UBC Campus
(UBC - Marti, Ventura, et al)

Building and water systems

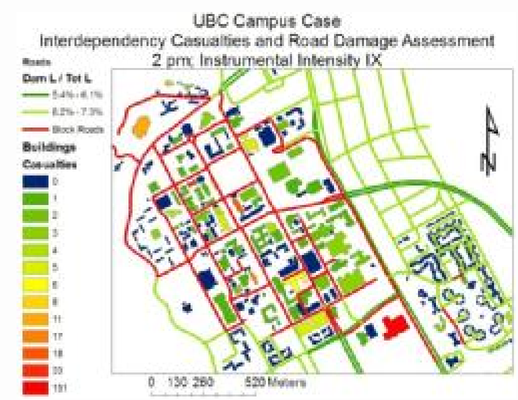
- Left: Separate damage assessment. After the earthquake, the majority of the buildings are non functional (orange colour: moderate to heavy damage) but many of the water pipes remain functional (green colour).
- Right: Considering interdependencies of both systems, the trunk line providing water to the water station has an accumulated loss of 8 %, but the water station is non-functional due to the extended damage to its structural and non structural components.





Buildings with casualty levels and road damage assessment

- The effect of the interdependency between the buildings with casualties across campus and the road blocks needed to place emergency units to assist injured people.



Analyzing Infrastructure for Disaster Resilient Communities (AIDRC)

(UBC – McDaniels, Chang, Reed, et al)

Basic Earthquake Scenario

Infrastructure Interviews

- Verification of scenario
- Upstream interdependencies
  - Which infrastructures?
  - Expectations regarding their disruption in scenario?
- Own system disruptions
  - Immediately, at 72 hours, at 2 weeks?
- Downstream interdependencies
  - Expected consequences?
  - Cross-sector planning?
- Mitigation priorities
  - Own sector?
  - Other Sector?

Past Earthquakes

Scholarly Literature

Data synthesized into diagrams

Workshop

Review Basic Scenario, Infrastructure Interviews, and Interdependency Diagrams

- Service Disruptions
- Interdependencies
- Cross-sectoral Expectations

Construct Detailed Scenario

Identify Major Regional Concerns

- Interdependencies
- Impacts

Mitigation and Preparedness Strategies

Analyzing Infrastructure for Disaster Resilient Communities (AIDRC)

(UBC – McDaniels, Chang, Reed, et al)

Infrastructures Interviewed

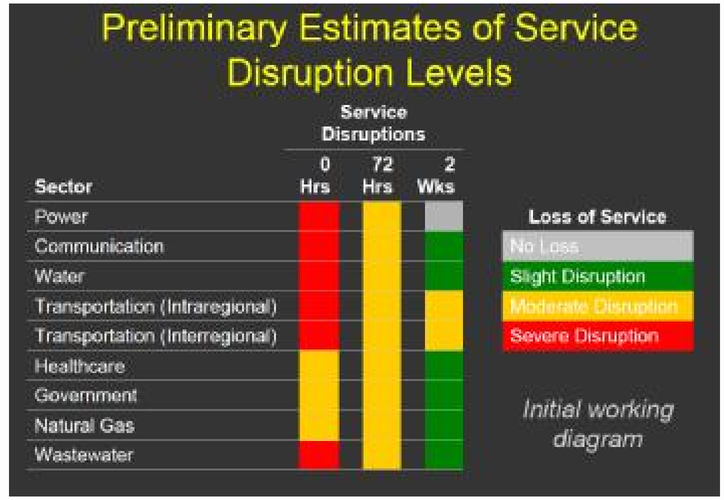
Utilities
- BC Hydro
- MetroVancouver (water & wastewater)
- Terasen Gas

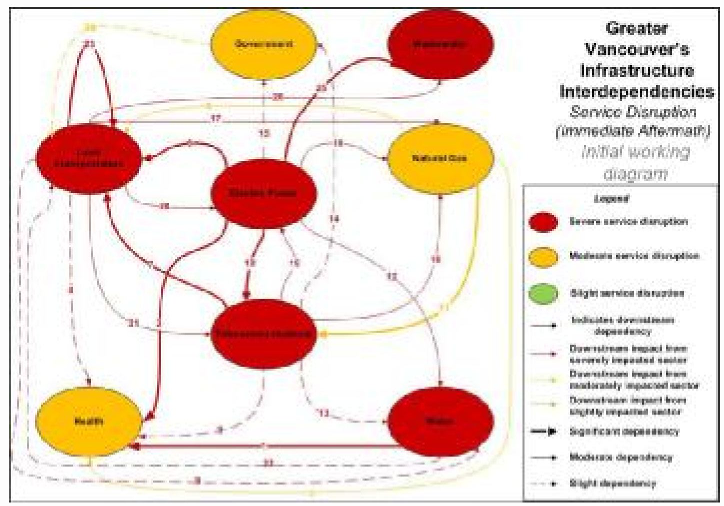
Transportation
- Ministry of Transport
- Translink
- Airports (YVR and Abbotsford)
- Port of Vancouver

Telecom
- Telus

Health
- Fraser Valley Health Authority
- BC Childrens & Womens Hospital

Government
- BC PEP
- Coquitlam (municipality)
- JELC





Designing Our Study

	JIIRP – UBC	AIDRC – UBC	Our Study
Data	Engineering	Empirical observation, Experts	
Focus	Systems	Systems	
Context	Single event (simulation)	Single event (scenario)	
Emphasis	Engineering	Societal impacts	
Outcome	Simulation tool	Scenario ranked strategies	
Purpose	Emergency Response	Mitigation and preparedness	

Lifeline Interdependency:

"As does a human body, a city has lifelines…

The failure to function of one of the lifelines, or its severe impairment, brings… damage or disaster to the city. Knowledge of the risk of such failures is a stimulus for preventive measures.

The <u>acceptable level of risk is established</u> by the individual for his body and <u>by the citizenry for the city</u>."

– C. Martin Duke (1972)

"Founder of Lifeline Earthquake Engineering in the U.S."

Potential "Hybrid" Approach for Our Study
(for Discussion Purposes Only)

- Conduct a scenario-based study (CAPSS and 2006 study of repeat of 1906 scenario data available for analyses)
- Study emphasis will be on response and restoration preparedness and coordination, and development of Lifelines Council (Resilient SF) performance standards (SPUR Resilient City standards available for baseline)
- Working group develops a series of questions that each operator is to answer about system performance, upstream and downstream inter-dependencies, and preparedness and coordination strategies/issues
- Each operator performs analysis of system performance and responds to questions. (Detailed system/asset data maintained by each operator
- Data synthesis and potential interviews or a group workshop to evaluate responses, interdependencies
- Prepare more detailed scenario with key interdependency issues identified
- Draft Lifelines Council performance standards, preparedness and coordination strategies

CAPSS and/or 2006 EERI Study of M7.8 on N San Andreas scenario data available

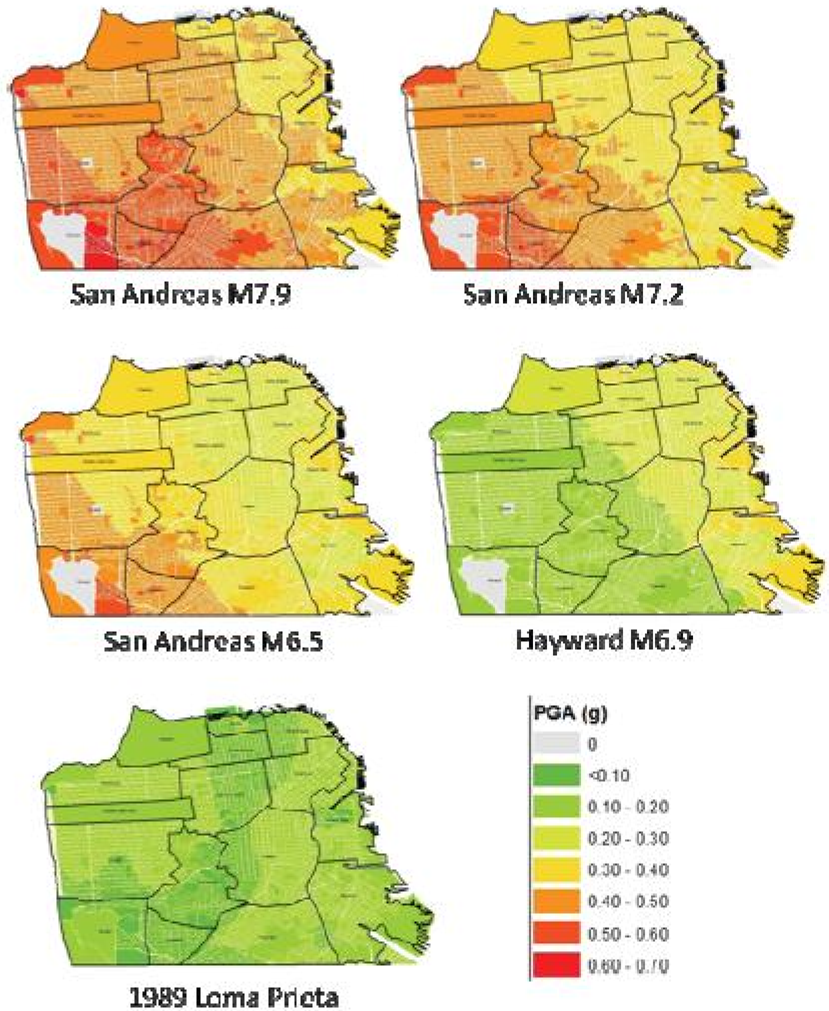
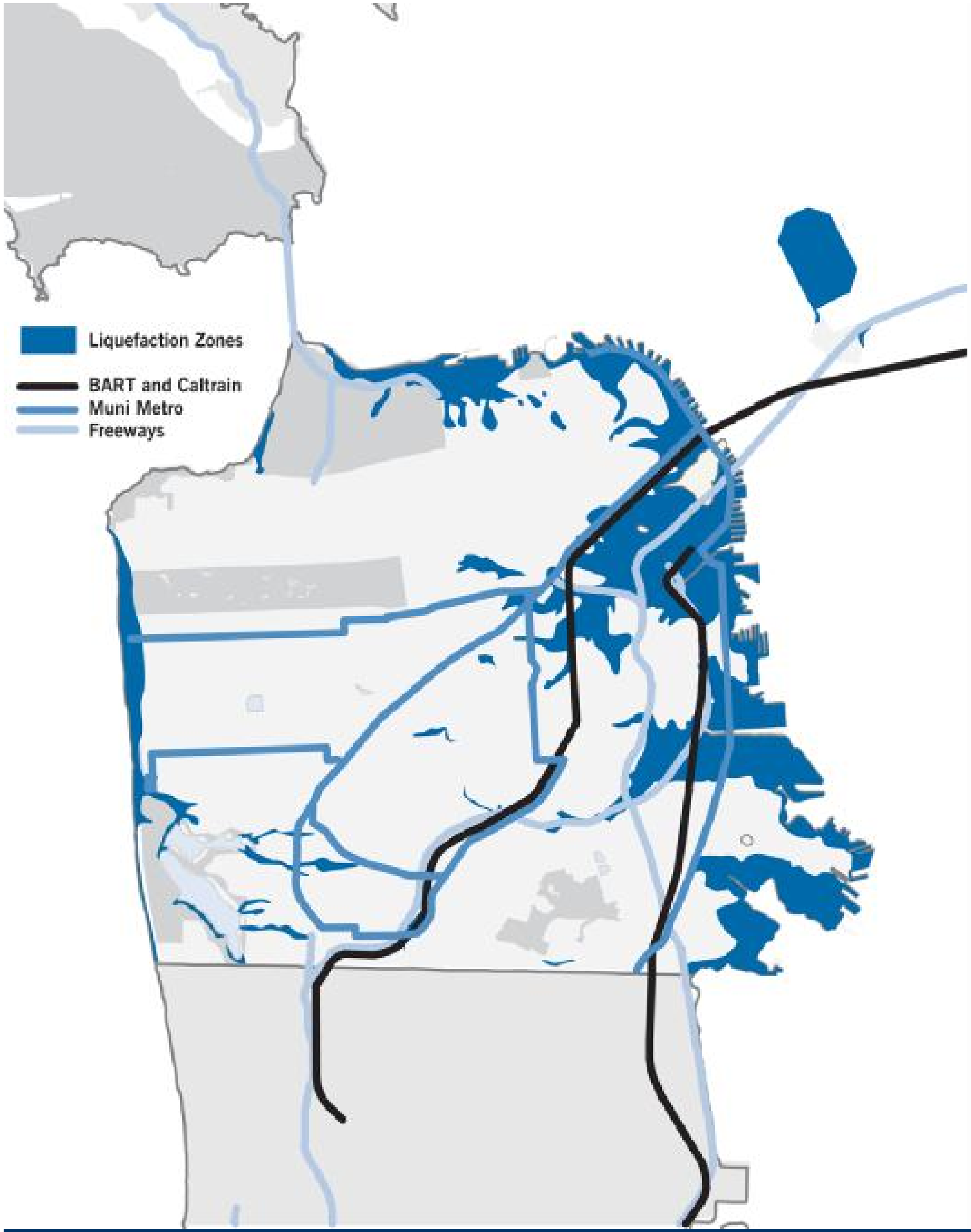


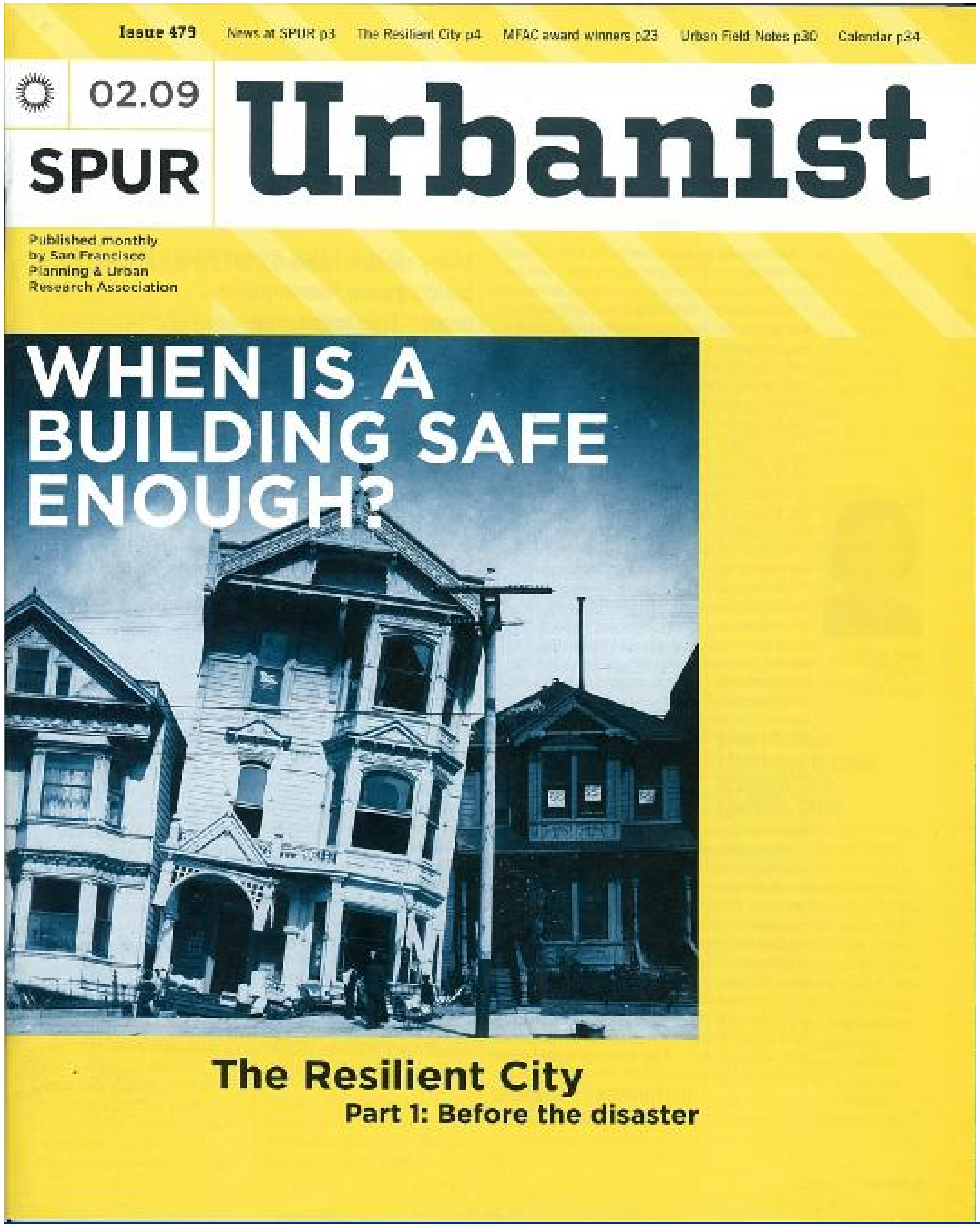
Figure 1 *The estimated shaking for the four scenario earthquakes, and the actual shaking experienced in the 1989 Loma Prieta earthquake. PGA stands for Peak Ground Acceleration, expressed as a percent of the acceleration of gravity.*



Scenario and data modifications may be needed to address special study areas, such as liquefaction zones

Source: California Department of Conservation, Division of Mines and Geology, final edition February 2003

http://gmw.consrv.ca.gov/shmp/download/pdf/ozn_sf.pdf



Before the Disaster

Defining what San Francisco needs from its seismic mitigation policies

www.spur.org

Target States of Recovery for Buildings and Infrastructure

TARGET STATES OF RECOVERY FOR SAN FRANCISCO'S BUILDINGS AND INFRASTRUCTURE

INFRASTRUCTURE CLUSTER FACILITIES	Event occurs	Phase 1 Hours			Phase 2 Days		Phase 3 Months		
		4	24	72	30	60	4	36	36+
CRITICAL RESPONSE FACILITIES AND SUPPORT SYSTEMS									
Hospitals								X	
Police and fire stations			X						
Emergency Operations Center	X								
Related utilities						X			
Roads and ports for emergency				X					
CalTrain for emergency traffic					X				
Airport for emergency traffic				X					
EMERGENCY HOUSING AND SUPPORT SYSTEMS									
95% residence shelter-in-place								X	
Emergency responder housing				X					
Public shelters							X		
90% related utilities								X	
90% roads, port facilities and public transit							X		
90% Muni and BART capacity						X			

TARGET STATES OF RECOVERY

Performance measure	Description of usability after expected event: BUILDINGS	LIFELINES
	Category A: Safe and operational	
	Category B: Safe and usable during repairs	100% restored in 4 hours
	Category C: Safe and usable after moderate repairs	100% restored in 4 months
	Category D: Safe and usable after major repairs	100% restored in 3 years
X	Expected current status	

Note: Categories A–D are defined on page 10.

Expected Performance of Lifelines

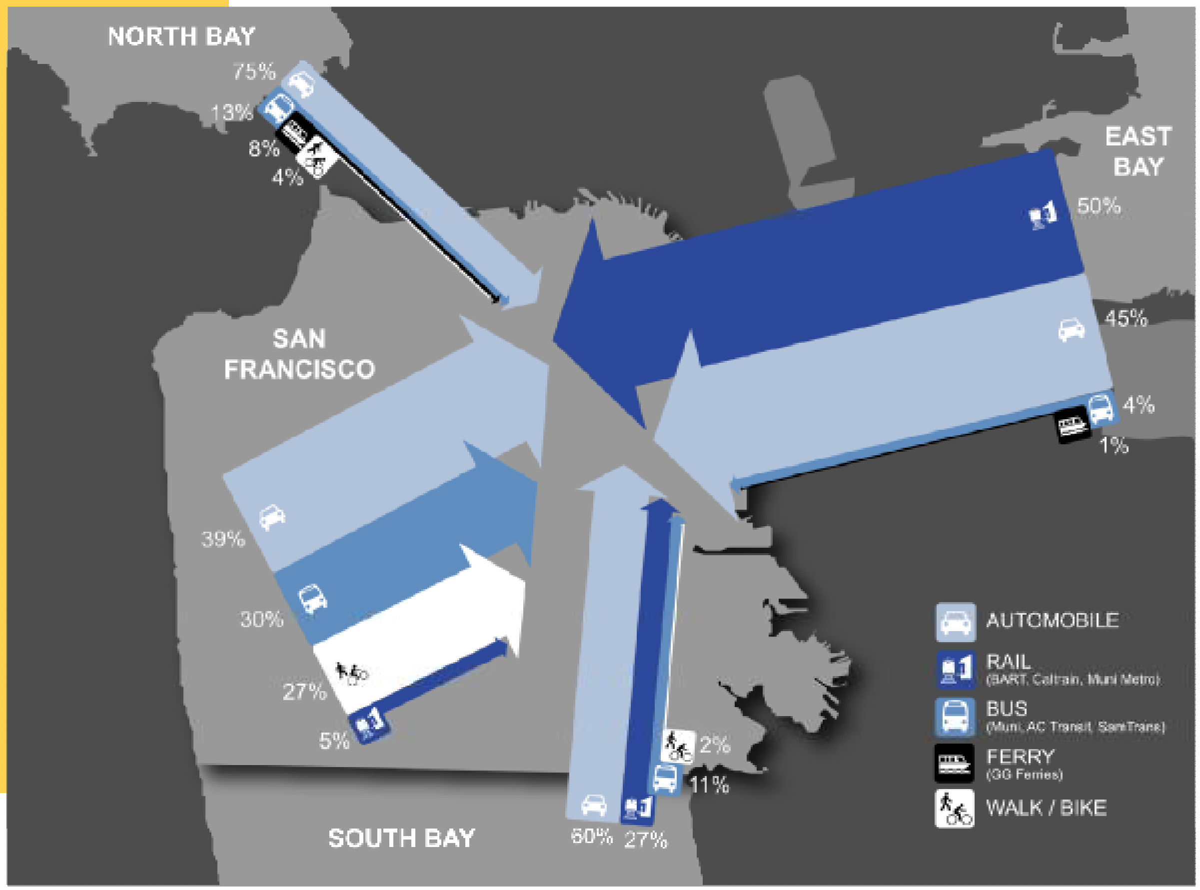
Category	Goals for Lifeline Service Restoration
I	100% restored in 4 hours, with backup systems if necessary
II	- Resume 90% of service within 72 hours - Resume 95% of service within 30 days - 100% restored in 4 months
III	100% restored in 30 years

Defining Specific System Performance Goals

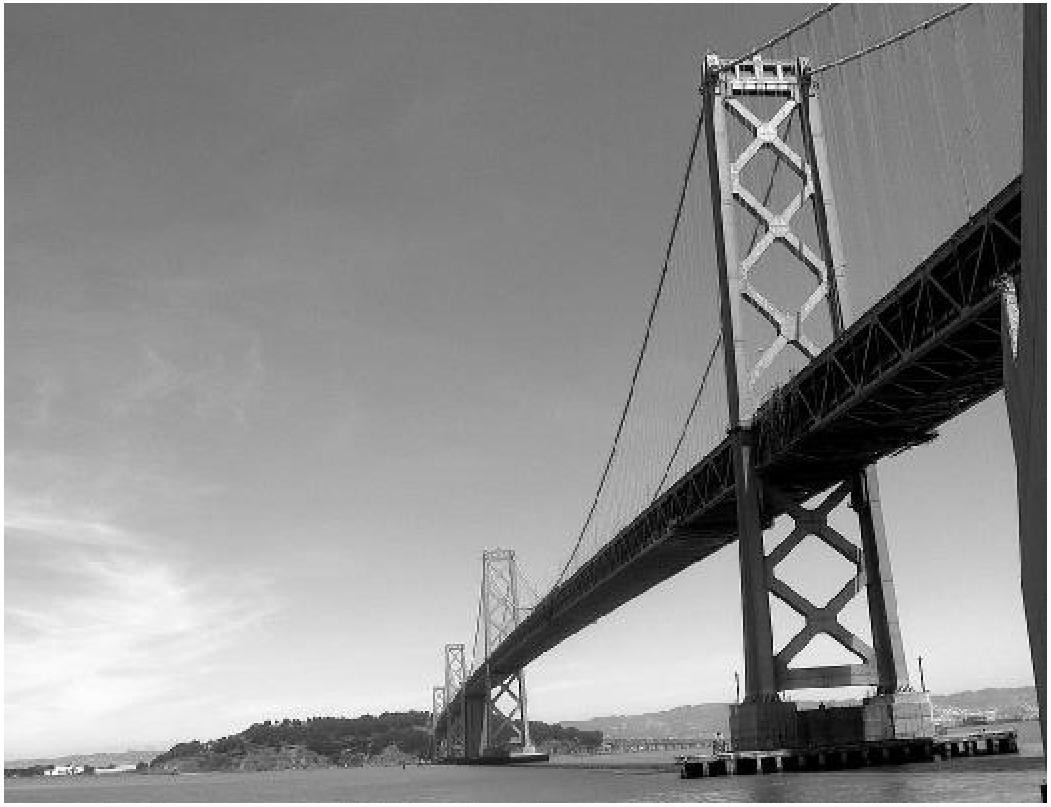
System	Target State of Recovery
Municipal Water System	Water or temporary supplies available to 100% of critical facilities within 4 hours; 90% of customers in 3 days; 95% of customers in 30 days
Auxiliary Water System	Water available for firefighting in 100% of city neighborhoods within 4 hours
Electric Power	Power or temporary supplies available to 100% of critical facilities within 4 hours; 90% of customers in 3 days; 95% of customers in 30 days
Natural Gas	Immediate control/shut-off where damage is likely; restore service to 95% of customers in non-liquefaction zones in 3 days; 95% of customers in 30 days
Telecom	Service available to 100% of critical facilities within 4 hours; 90% of customers in 3 days; 95% of customers in 30 days
Highways and Roads	City-identified priority routes open in 4 hours; bridge evaluations complete in 3 days; 90% of bridges open in 3 days; 90% of routes open in 30 days
Port	Critical ferry facilities open in 4 hours; 90% of ferry capacity restored in 3 days; 125% of ferry capacity available in 30 days
Transit	90% of MUNI, BART capacity restored in 3 days; service restored to 90% of customers in 30 days
Airport	Open for emergency traffic/evacuation flights in 3 days; open for commercial traffic in 30 days

MODAL SHARE FOR TRIPS THROUGH AND TO SAN FRANCISCO

line thickness proportional to gross trips



East Bay



Scenario A: Bay Bridge Intact, Transbay Tube Closed

Scenario B: Transbay Tube Intact, Bay Bridge Closed

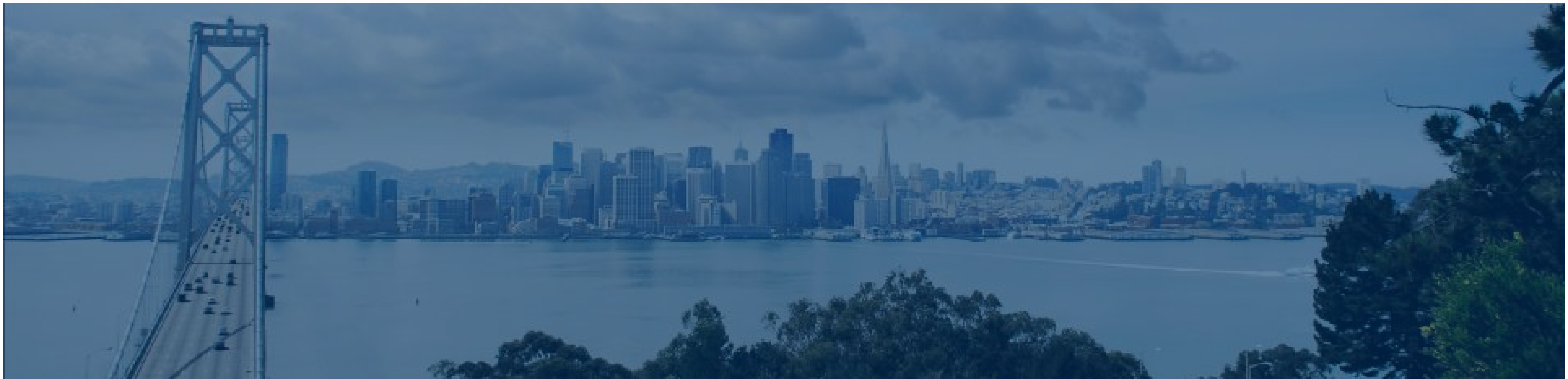
Scenario C: Both Bay Bridge and Transbay Tube Closed

EAST BAY: Before the Disaster Tool Kit

Action Item	Responsible Agency
Create a plan to coordinate bus bridges across the Bay Bridge	AC Transit, BART and Caltrans
Create permanent bus-only lanes on approaching freeways to the Bay Bridge (I-80, I-580, and I-880).	Caltrans and AC Transit
Develop a Restricted Vehicle Plan.	Caltrans
Develop contraflow bus system.	Caltrans and MTC/BATA
Identify emergency park-and-ride locations.	MTC and local government
Develop emergency transit plans	MTC, BART and AC Transit
Establish an emergency reserve bus fleet.	AC Transit
Establish mutual aid agreements with other bus agencies.	AC Transit, MTC

Potential Next Steps
(for Discussion Purposes only)

- Establishing a small working group of Council members and other partners/advisors to design and advise on the study
- Operators identify internal working team to participate in the study
- Scenario development, modification, and data packaging
- Collect and analyze interdependency modeling studies and develop system performance and upstream and downstream interdependency analytics
- Develop study work program and launch analyses with all operators



Discussion

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