Earthquake Impact on Transportation and Utility Networks

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Consequence-Based Risk Management

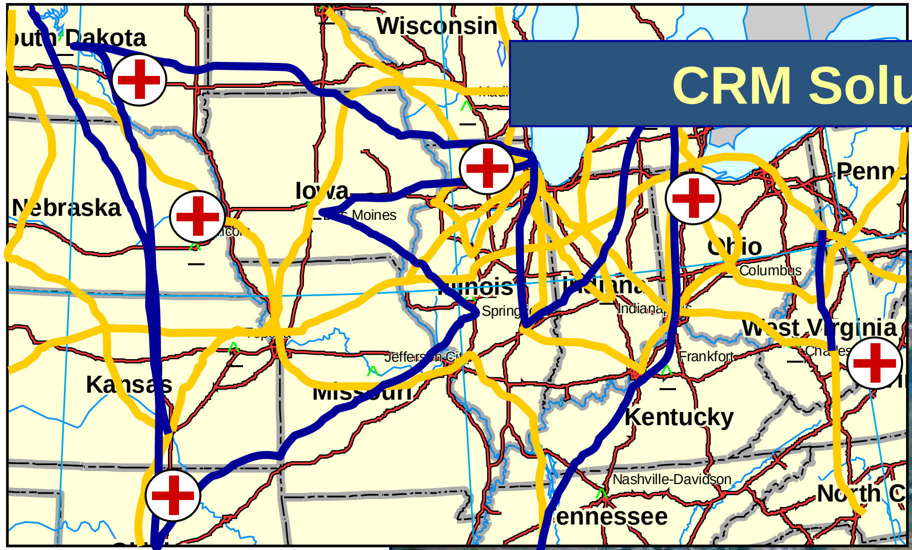
Engineering Solution

Consequence-Based Risk Management

Consequence-Based Risk Management

Mid-America Earthquake Center
Assessment, Response and Recovery

Consequence-Based Risk Management



CRM Solution

Network Solution

Engineering Solution

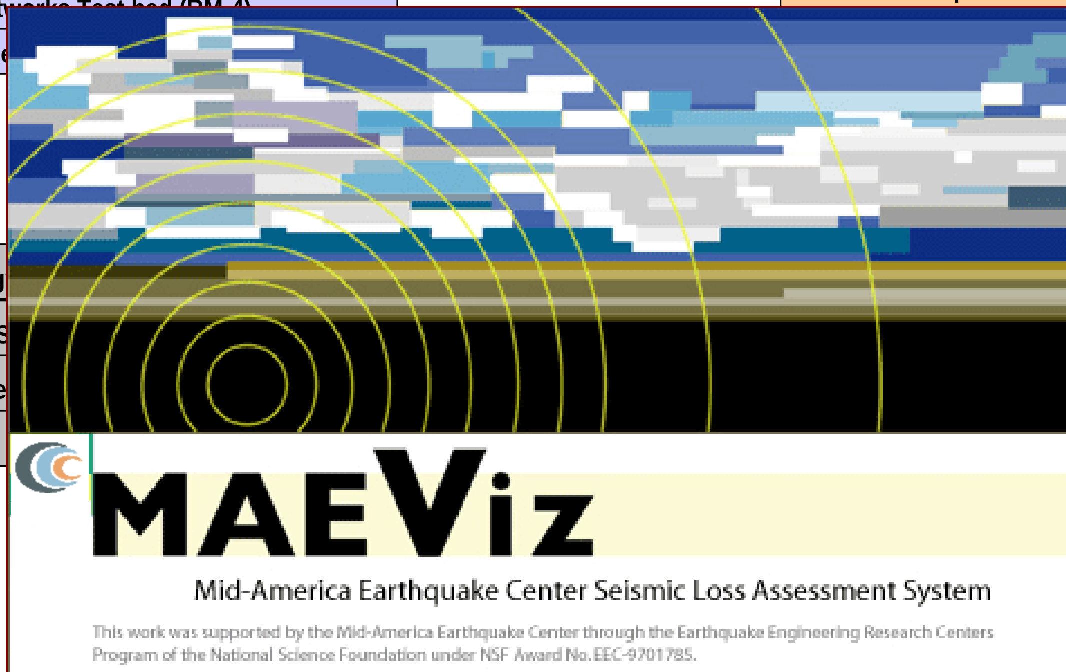
MAE Center Projects and MAEviz

- CRM Framework (RM-1)
- Systematic Treatment of Uncertainty (RM-2)
- Memphis Test bed (RM-3)
- Transportation Net
- Emergency Manage

- Decision and Risk Perception (SE-1)
- Quantitative Consequence Models (SE-2)
- Business Disruption Economic Loss (SE-3)
- E-4)

- Framework and Technolog
- MAEViz Portal within NEES
- User and Software Require
- Software Usability (IT-4)

- ons (EE-1)
- lels (EE-2)
- n Tools (EE-3)
- encies (EE-5)
- Technologies (EE-6)



- Seismic Path Modeling (HD-3)
- Site Modeling (HD-4)
- Verification of Site Response Paradigm (HD-5)

Pipe Network Damage in Earthquakes

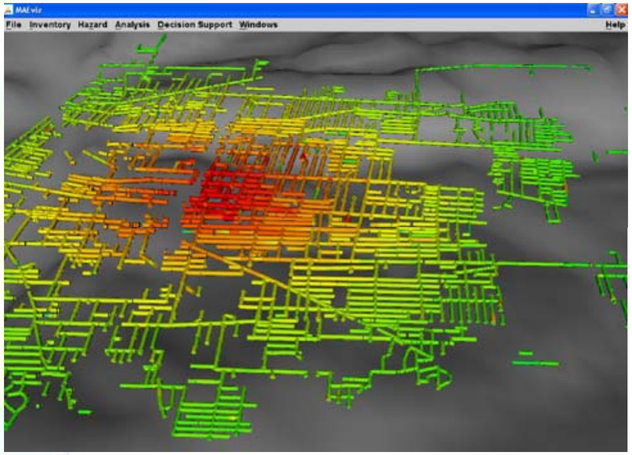
- **1994 Northridge Earthquake – Combined water and gas main break on Balboa Boulevard**

Pipe Network Damage in Earthquakes

- **Kobe earthquake 1995 – Fire following gas pipe rupture**

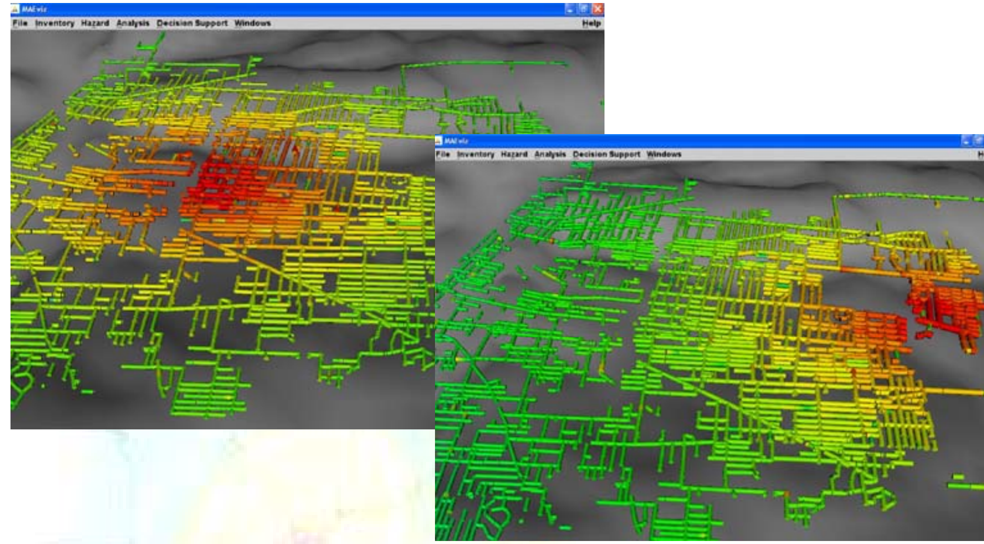
Description of MAEviz^{gas}

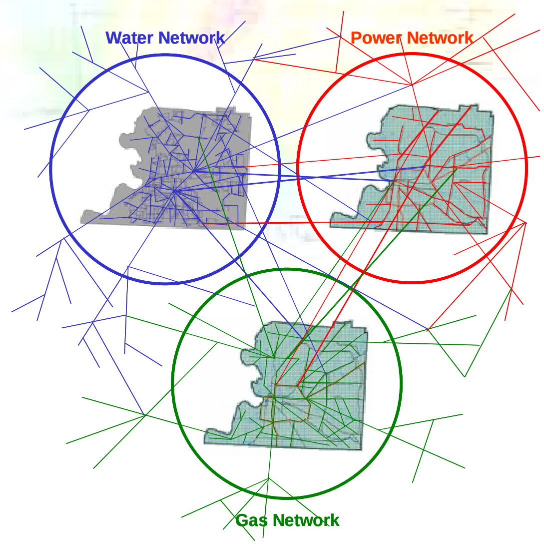
- **Setup**
  - Overlay ground topology
  - Overlay earthquake hazard maps for required return period
  - MAEviz Scenario Earthquake Dialog for generating specific events
  - Overlay pipeline Network
  - Load pipeline fragility (sensitivity) curves
  - Define Gas Network and Analysis Attributes
- **Analysis - Use**
  - Dialog for selecting network and analysis type
  - Damage estimates with suitable fragility curves
  - Repair estimates with suitable fragility curves
- **Visualization – Gas Pipeline network**
  - Colored by damage expectation
  - Colored by repair rate expectation
  - Select attributes and brush network for information
  - Colored and sized by estimated No. of repairs
  - Summary dialog for viewing and saving results



System Integration

- Customized MAEviz for comprehensive system-wide loss estimation and management for network systems
- Fragility of components other than pipes with retrofitting options
- State-of-the-art network flow analysis algorithm to quantify leakage, loss of pressure etc
- Tri-Network development (gas, electricity and water systems)



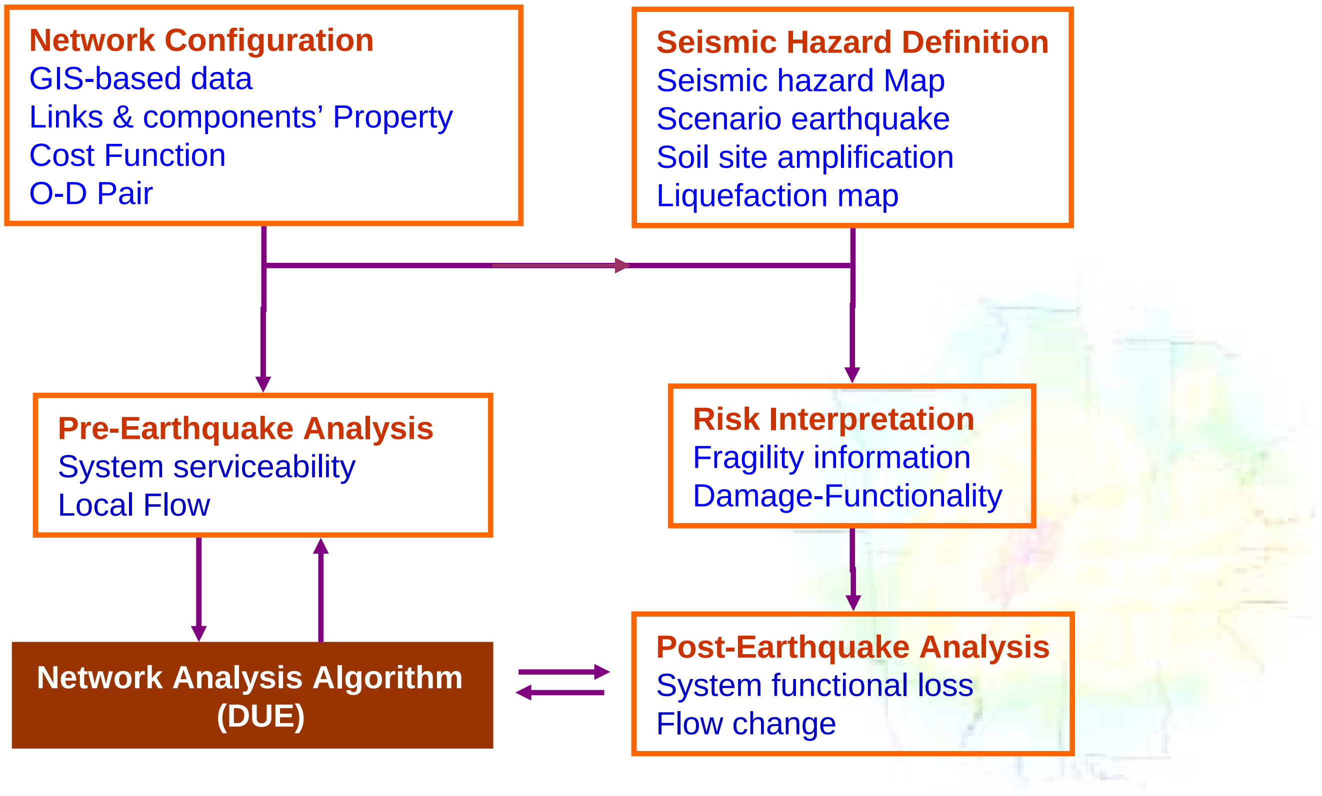


Transportation Systems and Earthquakes

- Recent urban earthquake
  - Loma Prieta Earthquake (1989, M_w=6.9)
    - Damage to 91 state bridges .
    - 13 bridges were closed.
    - The San Francisco Bay area experienced the most severe traffic disruption.
  - Northridge Earthquake (1994, M_w=6.7)
    - Damage to 286 state highway bridges.
    - Seven bridges in the portions of Interstate 10, California State Route 14, state route 118, and Interstate 5 are collapsed.
    - Significant travel time delay had been reported until the alternative routes were opened.
  - Hyogoken-Nanbu Earthquake (1995, M=7.2; JMA scale)
    - Heavy damage to highway structures in the Hanshin area.
    - Portions of Hanshin Expressway, Meishin National Expressway and Chugoku National expressway were collapsed.
    - Huge repair cost and economic impact.

San Francisco – Oakland Bay Bridge (Picture from USGS.gov)

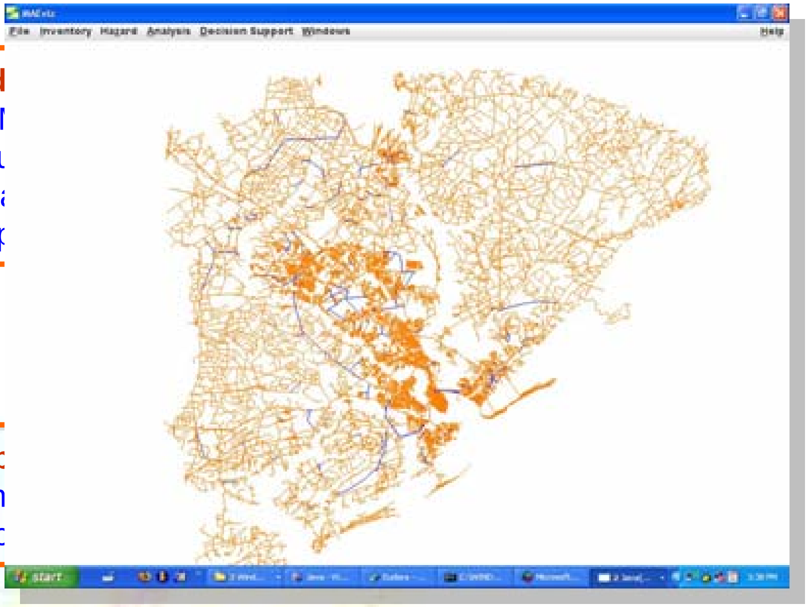
Methodology - Procedure



Methodology – Network Configuration

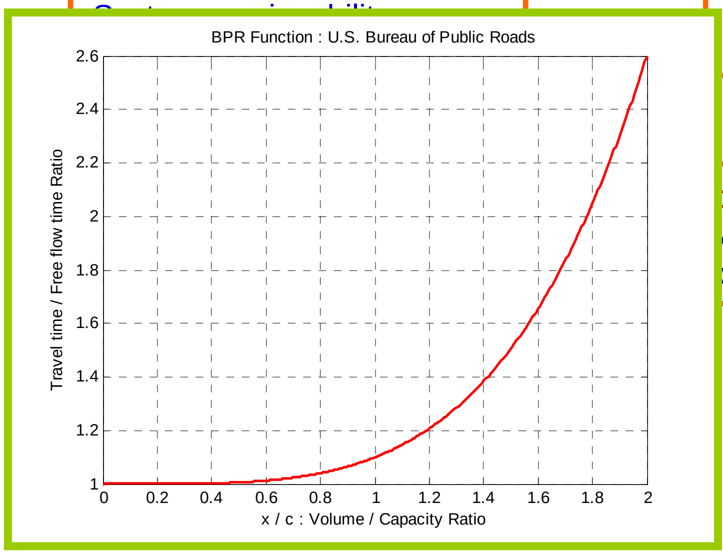
Network Configuration
GIS-based data
Links & components' Property
Cost Function
O-D Pair

Seismic Hazard
Seismic hazard I
Scenario earthqu
Soil site amplifica
Liquefaction map



Hazard Interp
Fragility inform
Damage-Func

Pre-Earthquake Analysis
Cost Function – BPR function



ost-Earthquake Analysis
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ow change

Link & Component Property
Link : No. of lanes, linkages, capacity, length free-flow speed, cost function parameters
Component : Structure Type, location

Seismic Hazard Definition

Network Configuration
GIS-based data
Links & components' Property
Cost Function
O-D Pair

Seismic Hazard
Seismic hazard M
Scenario earthqu
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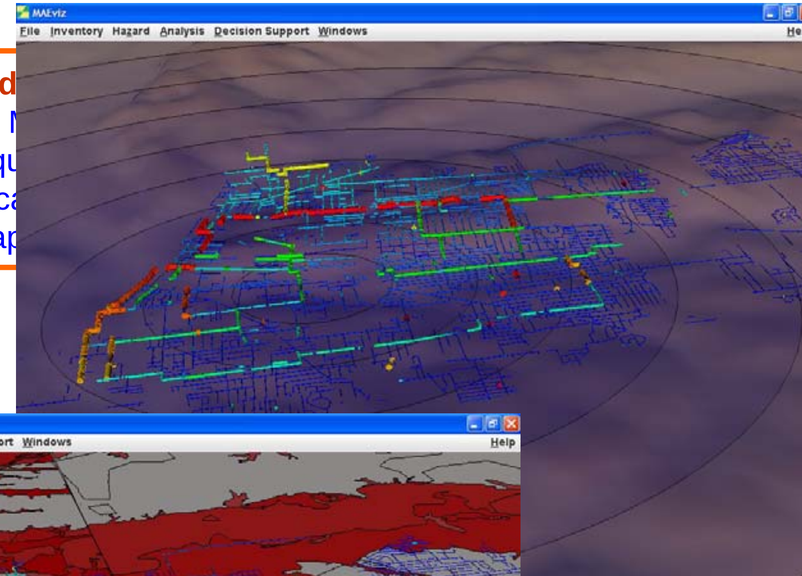
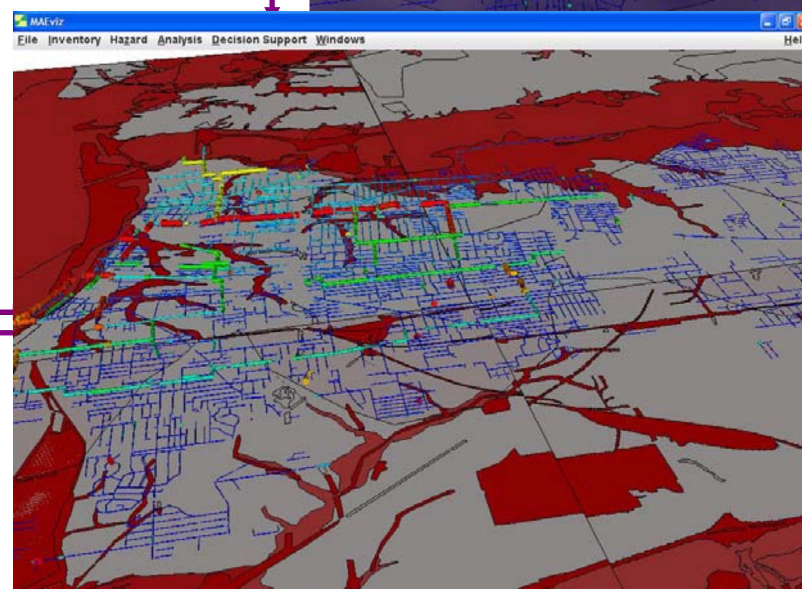
Liquefaction map



Pre-Earthquake Analysis
System serviceability
Local Flow



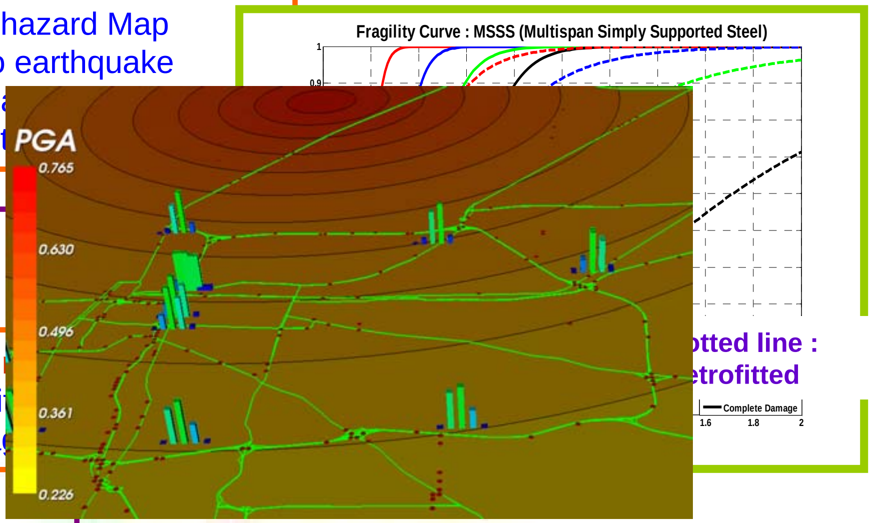
Network Analysis Algorithm (DUE)

Risk Interpretation

Network Configuration
GIS-based data
Links & components' Property
Cost Function
O-D Pair

Seismic Hazard Definition
Seismic hazard Map
Scenario earthquake
Soil site a
Liquefact

Applying Fragility Curves



Probability Distribution of Capacity Reduction

Pre-Earthquake Analysis
System serviceability
Local Flow

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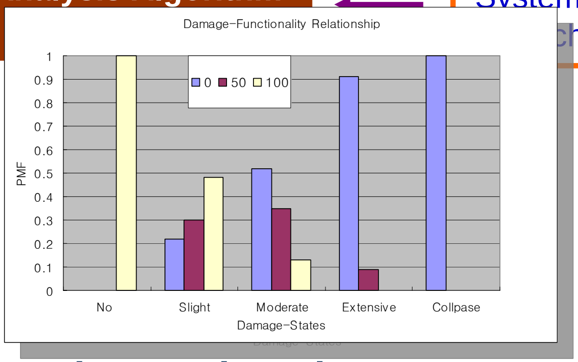
Applying Damage-Functionality Relationship

Network Analysis Algorithm



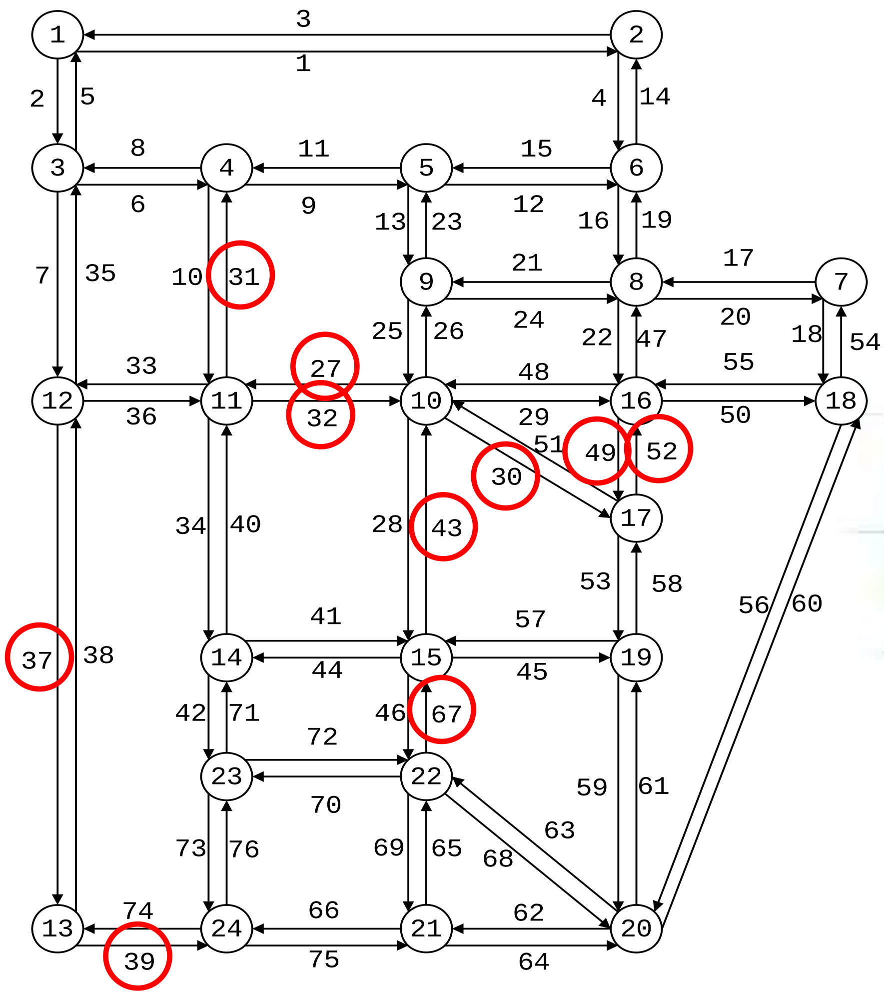
Post-Earthquake Analysis
System functional loss
change

Probability distribution of damage to bridges

Objective of Regional Assessment

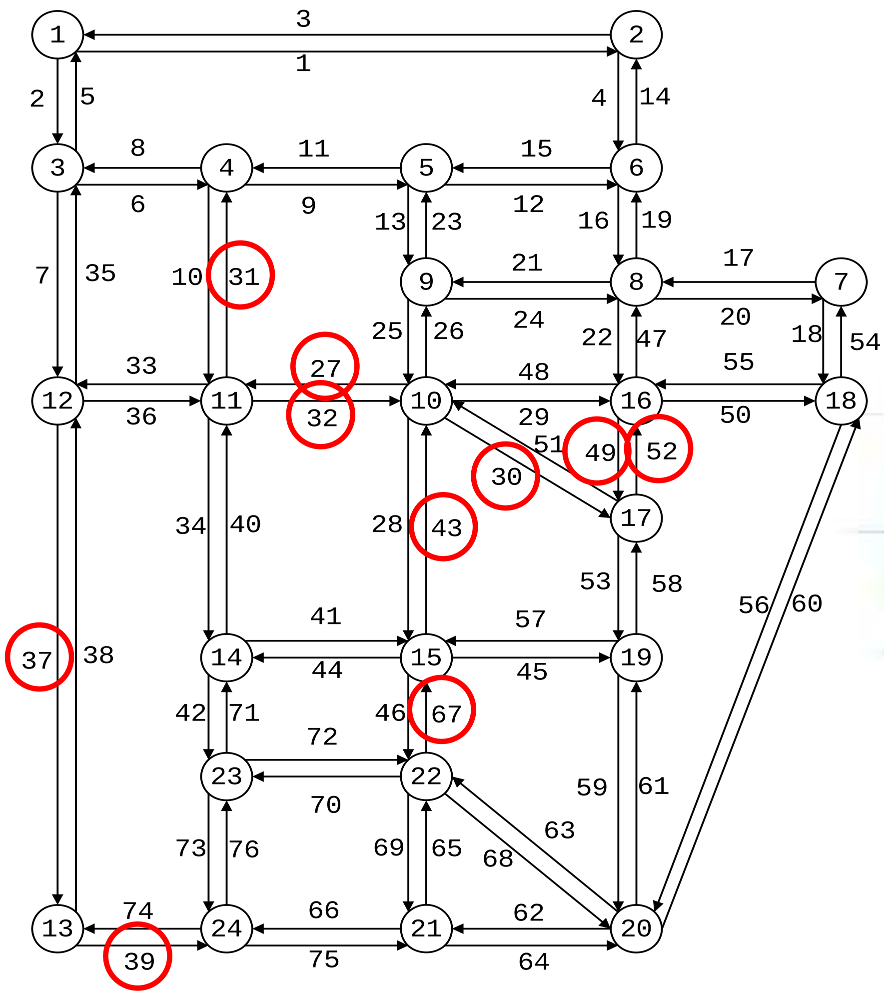
- Assess post-EQ system performance of transportation network system considering stochastic capacity reduction of bridges.
- Assess the post-EQ system performance under various scenarios. (e.g., failure of essential facilities and increment of traffic demand to utility (attractive) sites following earthquake)
- Total System Travel time (TSTT) is used as a measure of a system performance.
- Determine optimal retrofit strategy for various scenarios

Sioux-Falls Network Model



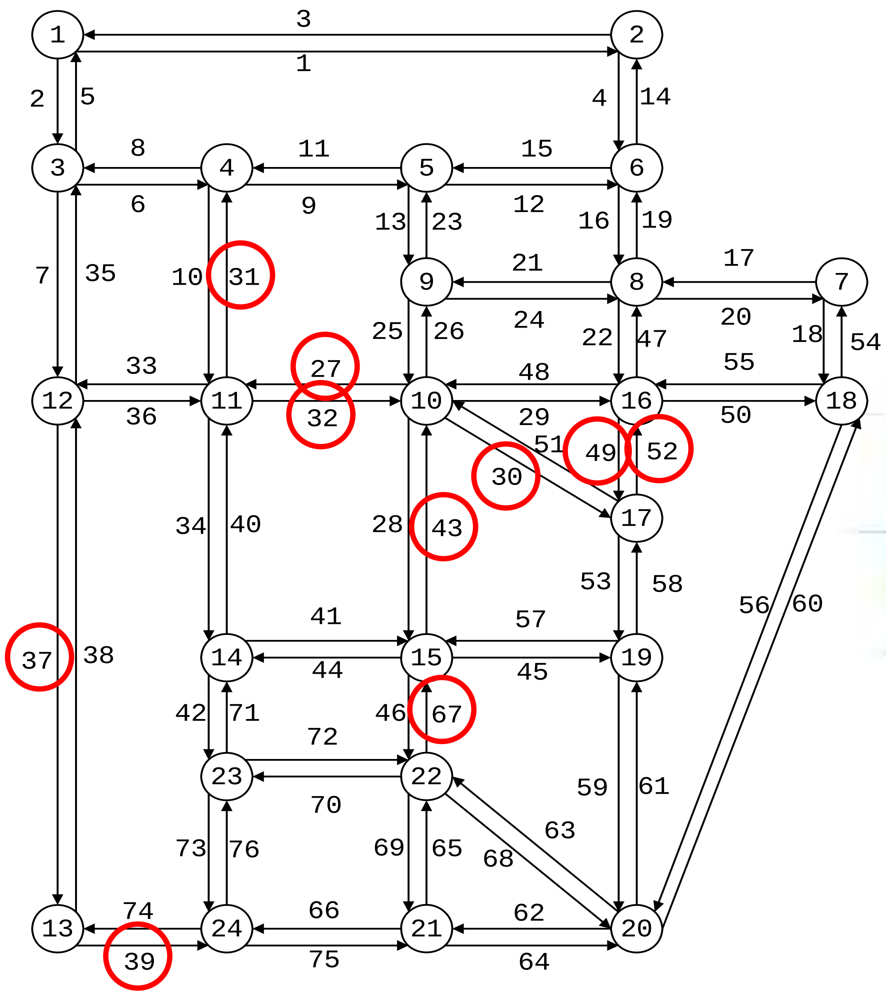
- 24 nodes & 76 inks
- Total Demand = 39644
- 10 bridges in the system (red-circled)

Scenarios Under Considerations

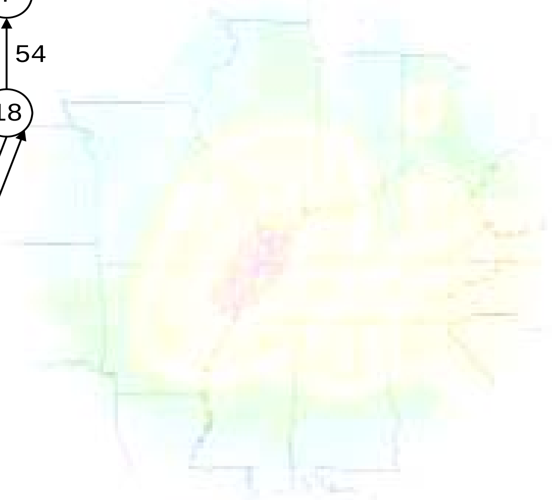


- **Case Study A**
  - Earthquake damages bridges
- **Case Study B**
  - Earthquake damages bridges
  - Repellent areas (e.g.fire) appear
- **Case Study C**
  - Earthquake damages bridges
  - Attractant sites (e.g. hospitals) appear

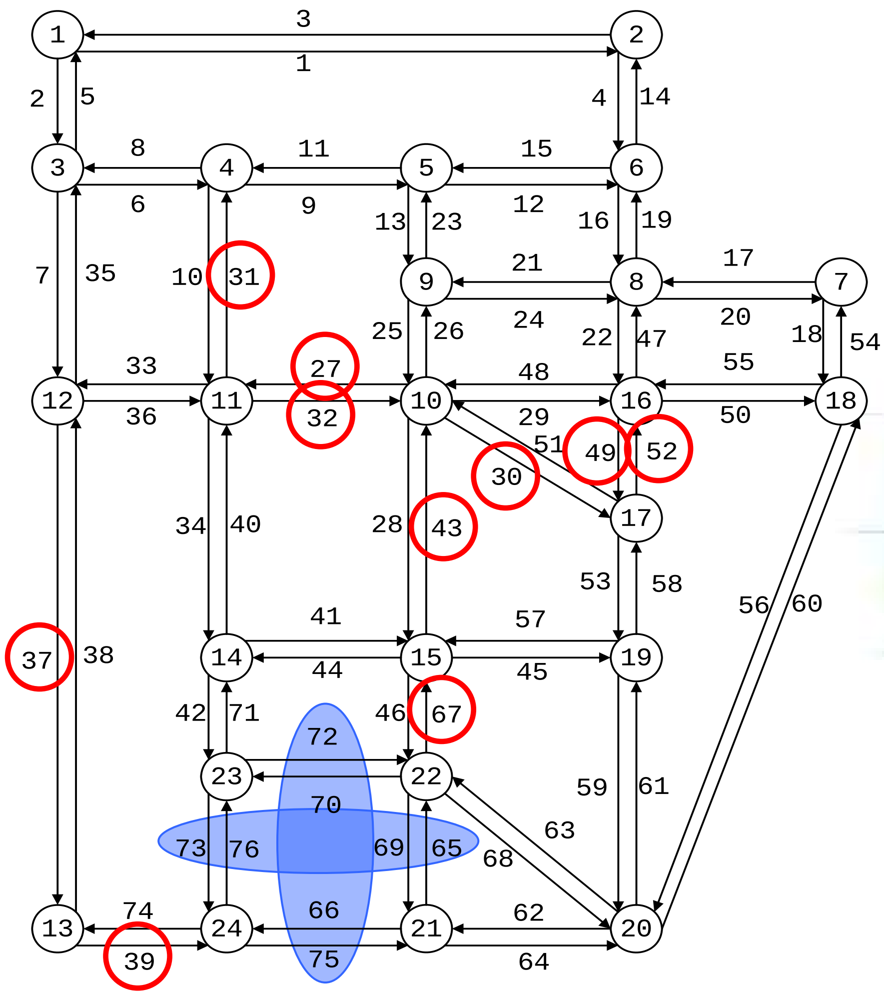
Case Study A



- Earthquake damages bridges
- Estimate system performance
- Estimate traffic flow



Case Study B

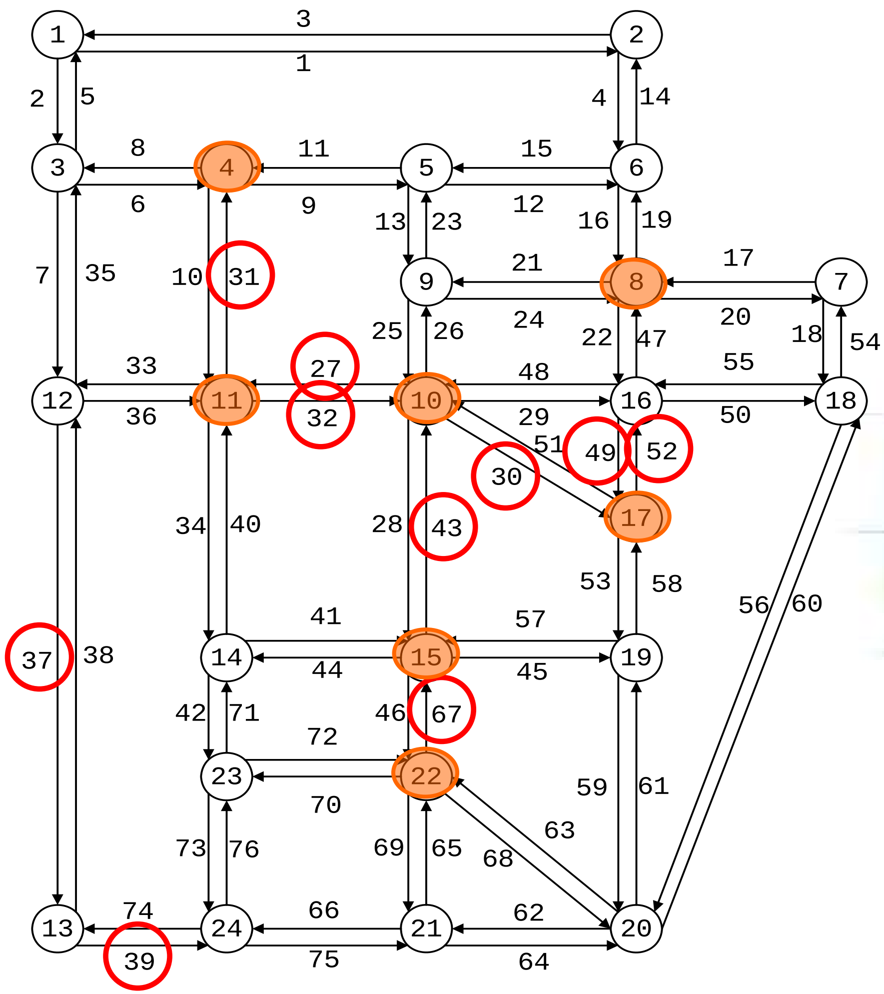


- Earthquake damages bridges
- Repellent areas appear

  (e.g., release of hazardous material, explosion of power plant, fires etc)

  Blue-shaded regions
- Links in the repellent areas have detours
- Estimate system performance
- Estimate traffic flow

Case Study C

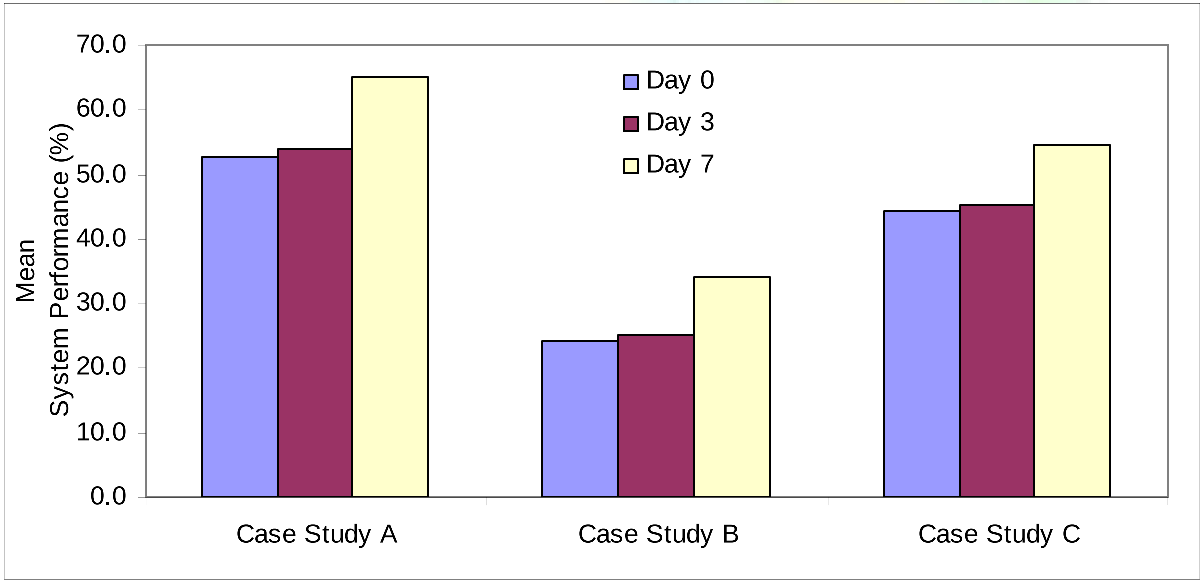


- Earthquake damages bridges
- Attractant sites appears
- (e.g., hospitals, shelters, etc) Orange-shaded traffic zones
- Traffic demand to attractant sites (nodes) is assumed to be increased by 30% of their original demand
- Estimate system performance
- Estimate traffic flow

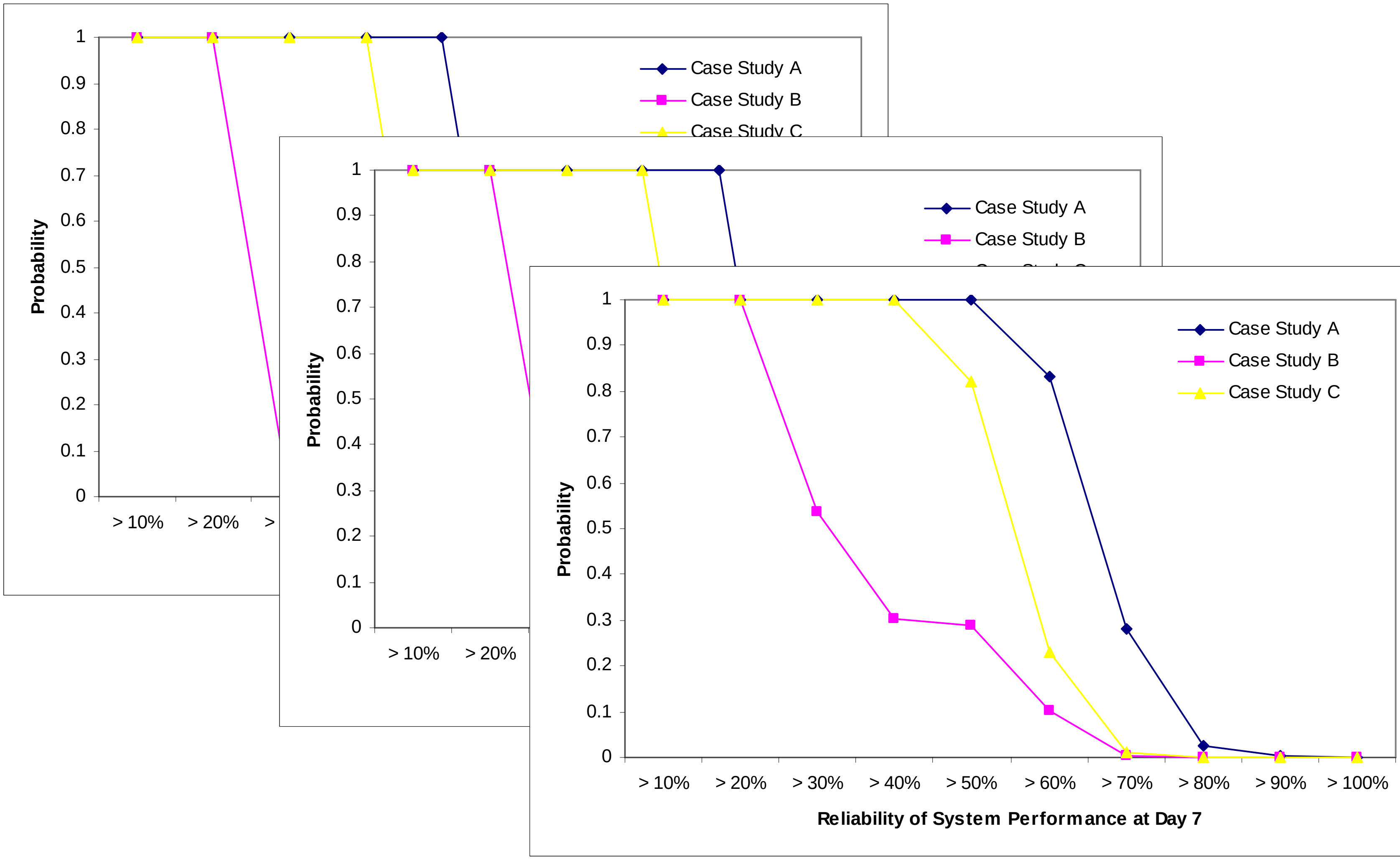
Post-Earthquake Analysis

- **System performance of the case studies**

Time	Case Study A	Case Study B	Case Study C
Day 0	52.790	24.277	44.245
Day 3	54.010	25.107	45.253
Day 7	65.079	33.963	54.593

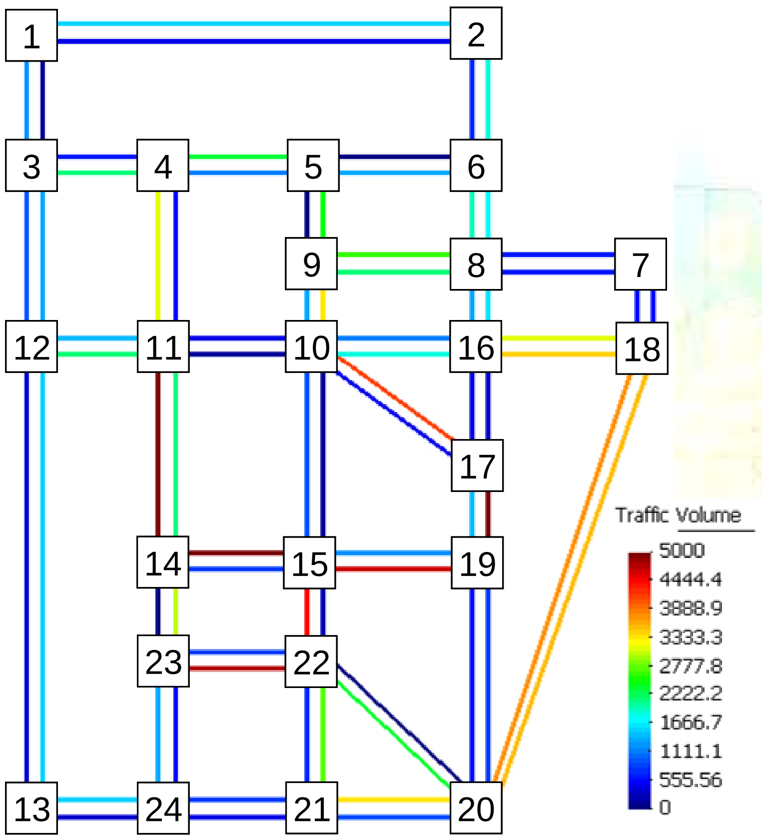


Post-Earthquake Analysis



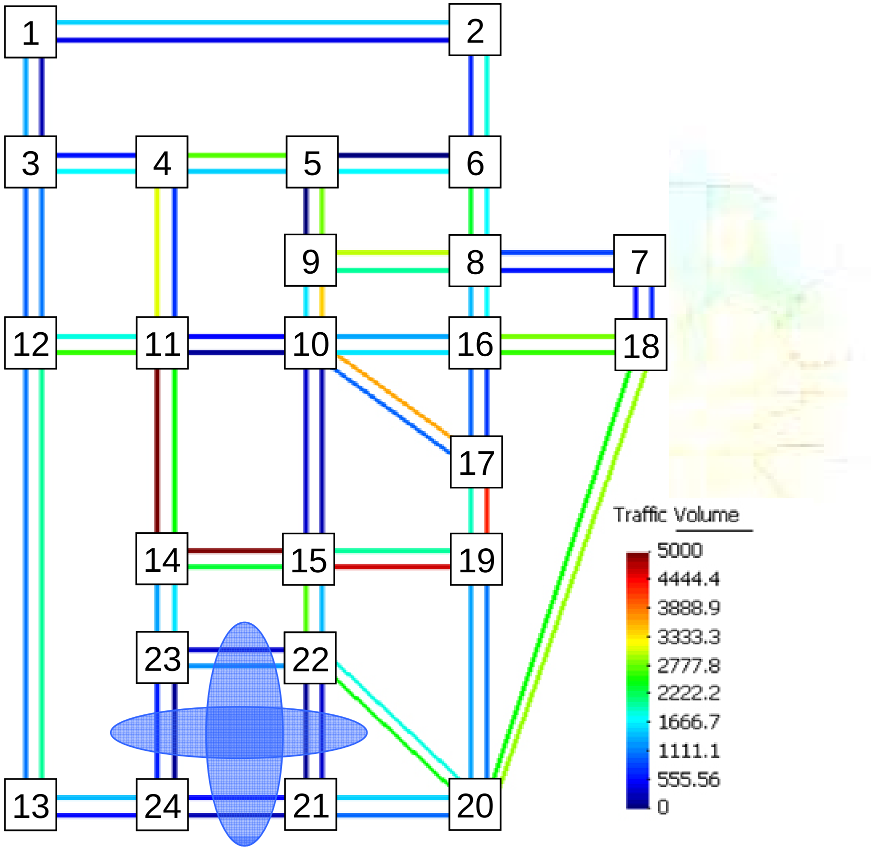
Post-Earthquake Analysis (Ctd')

- **Traffic Flow at Day 0: Case Study A**



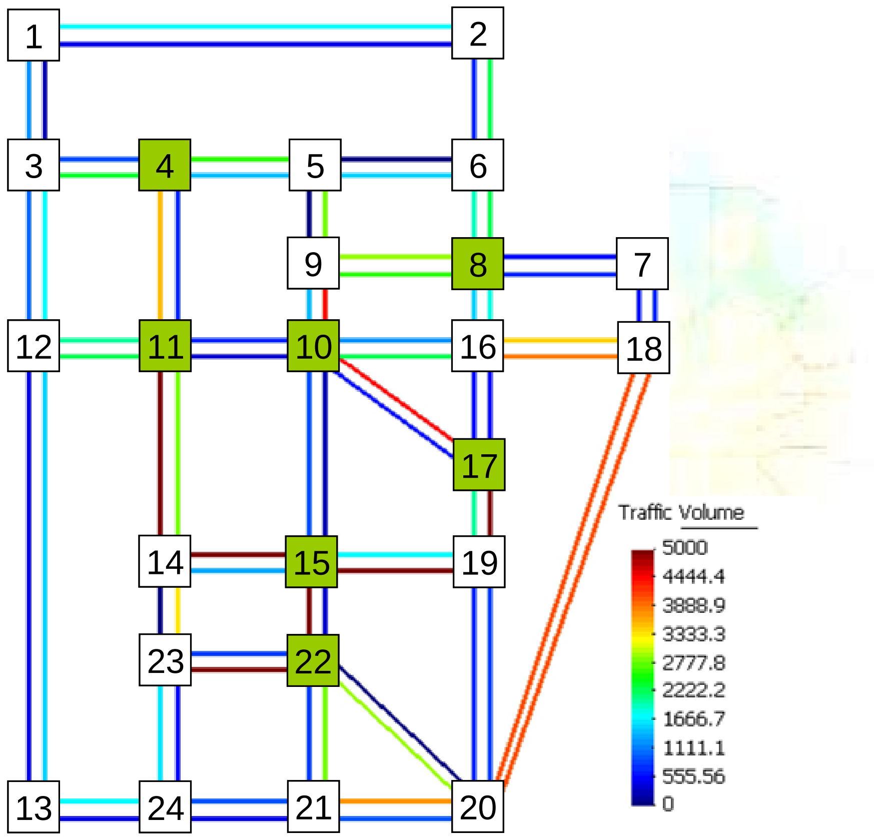
Post-Earthquake Analysis (Ctd')

- **Traffic Flow at Day 0: Case Study B**



Post-Earthquake Analysis (Ctd')

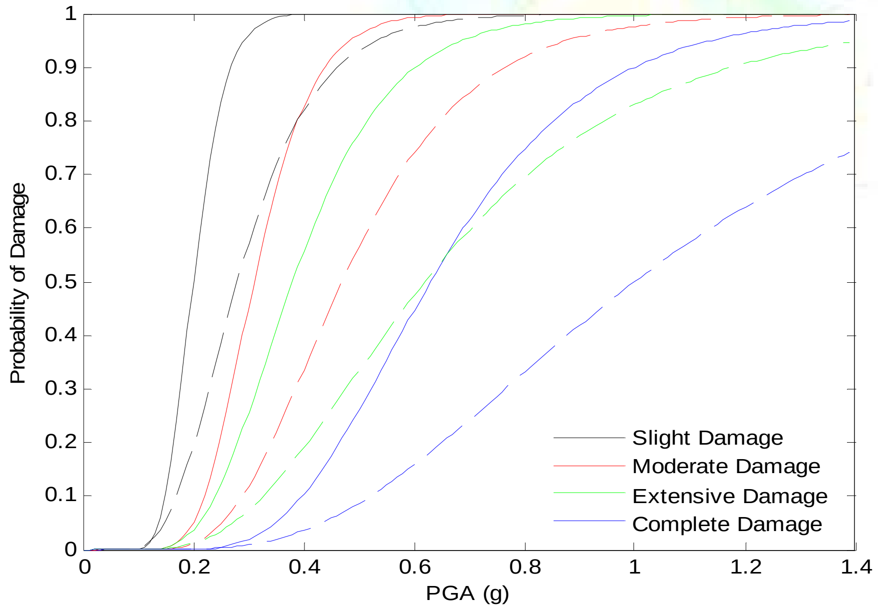
- **Traffic Flow at Day 0: Case Study C**



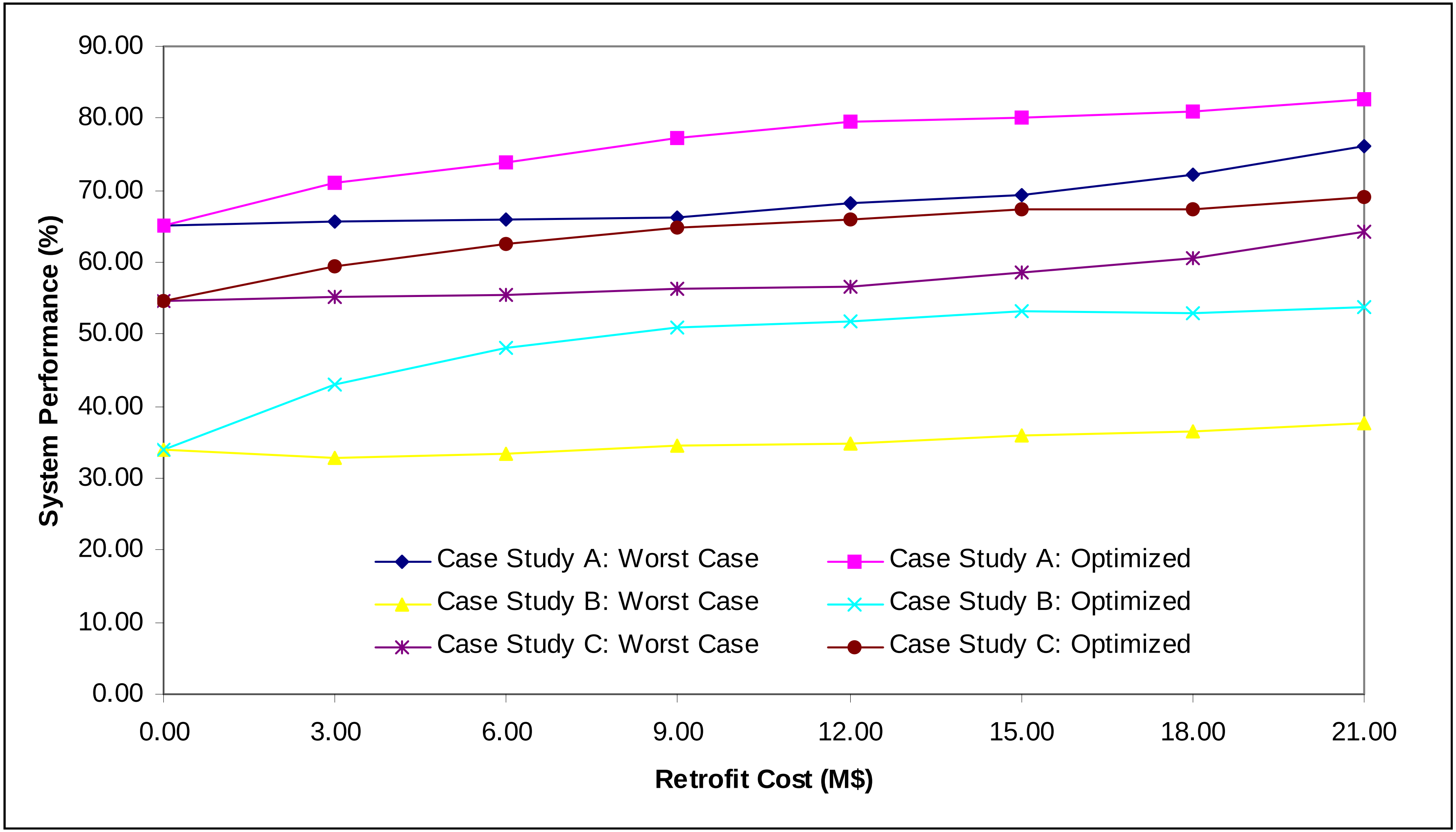
Optimization of Retrofit Strategy

- **Retrofit Cost = 2.2.M$ / mile / lane**
- **Fragility Curves for Retrofitted Bridge (LB: Lead-Rubber Bearing)**

Bridge Type		Slight		Moderate		Extensive		Complete	
		m(g)	β	m(g)	β	m(g)	β	m(g)	β
MSC Steel	As-Built	**0.20**	0.23	**0.31**	0.27	**0.38**	0.36	**0.63**	0.36
	LB	**0.28**	0.39	**0.47**	0.38	**0.62**	0.50	**1.00**	0.51



Retrofit Cost Analysis



Optimal Retrofit Strategy

Cost (M$)	Case Study A		Case Study B		Case Study C	
	Worst Case	Optimized	Worst Case	Optimized	Worst Case	Optimized
0	{}	{}	{}	{}	{}	{}
< 3	{52}	{32, 49}	{31}	{37, 43}	{67}	{27, 32}
< 6	{52, 67}	{32, 37, 43, 49}	{30, 31, 43}	{27, 31, 32, 37}	{39}	{27, 32, 37, 49}
< 9	{39, 67}	{27, 31 ,32, 37, 43, 49, 52}	{31, 39}	{32, 37, 43, 49, 67}	{39, 52}	{27, 31 ,32, 37, 43, 49, 52}
< 12	{31, 39, 67}	{27, 31 ,32, 37, 43, 49, 52, 67}	{30, 39, 49}	{27, 30, 31, 32, 37, 43, 52, 67}	{39, 52, 67}	{27, 30, 31, 32, 37, 49, 52}
< 15	{31, 39, 43, 52, 67}	{27, 30, 31, 32, 37, 43, 49, 52}	{30, 31, 32, 39, 49, 52}	{30, 31, 32, 37, 43, 49, 52, 67}	{30, 31, 39, 67}	{27, 30, 31, 32, 37, 43, 49, 52}
< 18	{27, 30, 31, 39, 52, 67}	{27, 30, 31, 32, 37, 39, 43, 52}	{27, 30, 31, 39, 43, 67}	{27, 30, 32, 37, 43, 49, 52}	{27, 30, 31, 39, 52, 67}	{27, 31, 32, 37, 39, 43, 49, 52, 67}
< 21	{27, 30, 31, 32, 39, 49, 52, 67}	{ all bridges}	{27, 30, 31, 39, 43, 49, 52, 67}	{27, 30, 31, 32, 37, 39, 49, 52, 67}	{30, 31, 37, 39, 43, 49, 52, 67}	{all bridges}

Conclusion

- The results show that post-earthquake traffic flow and system performance can be significantly affected not only by earthquake itself but also by the failure of other infrastructure systems.
- The results shows that optimal retrofit strategy for transportation network system solely based on earthquake damage to transportation may not be the optimum.
- Therefore, seismic retrofit for transportation system need to take into account damage and utilities failure in the region.
- Whereas we are struggling to convince decision-makers to invest in lifeline loss assessment and mitigation, analyzing one network in isolation is inadequate.