# EARTHQUAKE LOSS ESTIMATION OF St. LOUIS TRANSPORTATION HIGHWAY SYSTEM

**Ronaldo Luna, Ph.D., P.E.**
Associate Professor of Civil Engineering
University of Missouri-Rolla (UMR)

Geotechnical and Bridge Seismic Design Workshop
*New Madrid Seismic Zone Experience*

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# EARTHQUAKE LOSS ESTIMATION OF St. LOUIS TRANSPORTATION HIGHWAY SYSTEM

Investigators (alphabetical order):

Genda Chen
Don Deardorff
Dave Enke
Dave Hoffman
Sripathy Jitta
Siasi Kociu
Bill Lawrence
Ronaldo Luna (Lead)
Gary Spring
Chakkaphan Tirasirichai
Ed Wang

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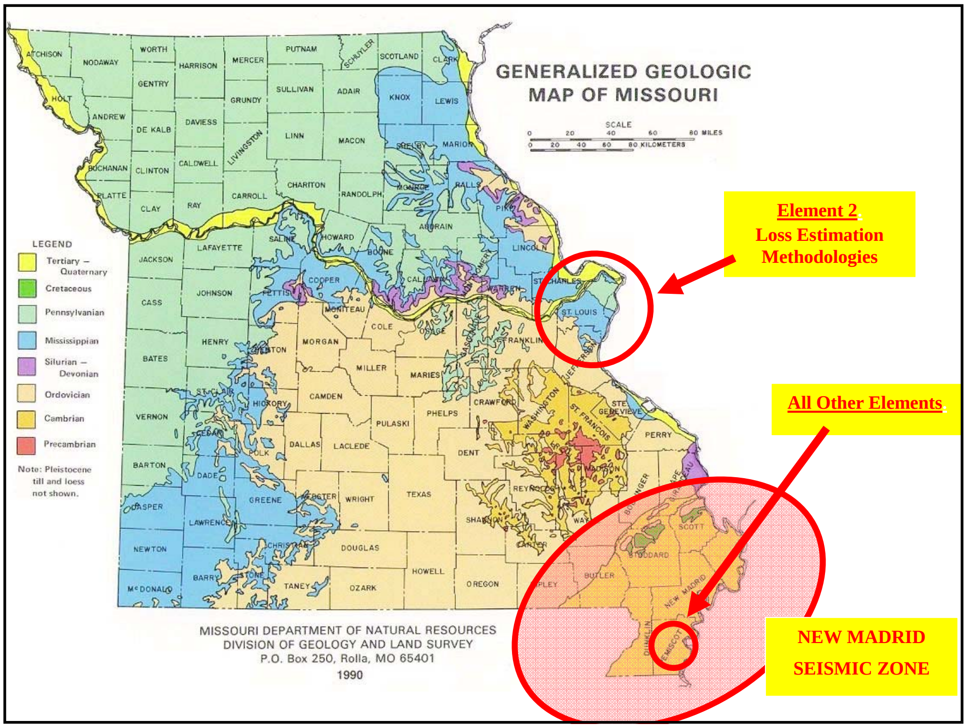
# Presentation Outline

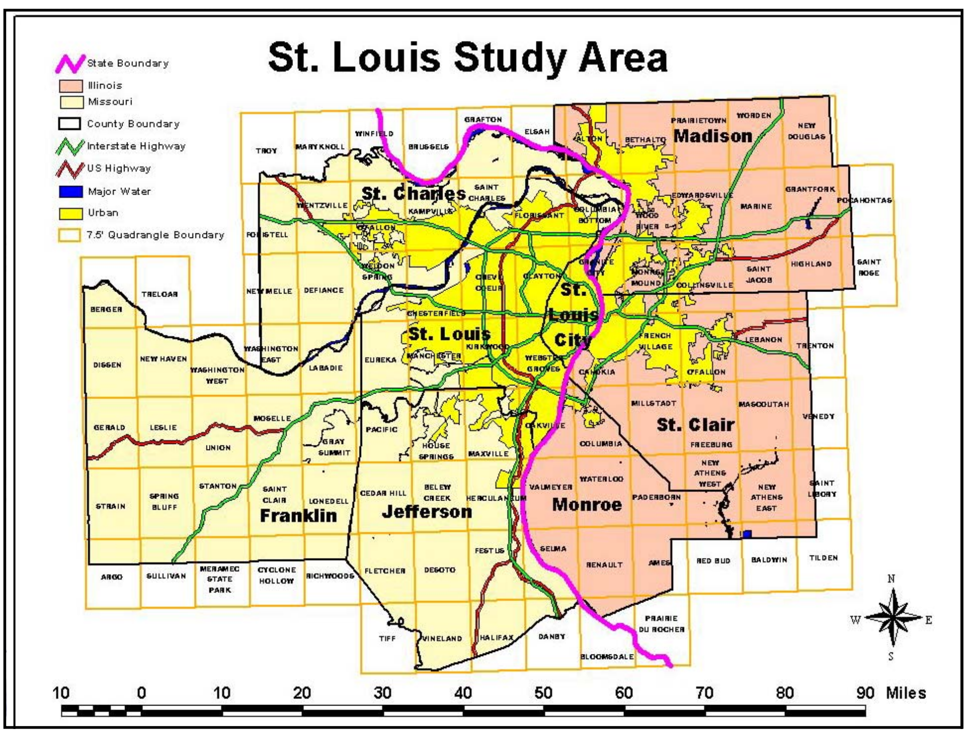
- Goals & Objectives
- Project Timeline
- EQ Loss Estimation Methodology
- Scenarios & Results
- Summary
- Questions/Comments



# FHWA Goal

- Develop or adopt an earthquake loss estimation procedure for earthquake damage to the highway system
  - Includes direct and indirect losses
- Demonstrate the methodology in the NMSZ area


GENERALIZED GEOLOGIC MAP OF MISSOURI
SCALE
0 20 40 60 80 MILES
0 20 40 60 80 KILOMETERS
LEGEND
Tertiary – Quaternary
Cretaceous
Pennsylvanian
Mississippian
Silurian – Devonian
Ordovician
Cambrian
Precambrian
Note: Pleistocene till and loess not shown.
MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY
P.O. Box 250, Rolla, MO 65401
1990
Element 2
Loss Estimation Methodologies
All Other Elements
NEW MADRID SEISMIC ZONE


St. Louis Study Area
State Boundary
Illinois
Missouri
County Boundary
Interstate Highway
US Highway
Major Water
Urban
7.5' Quadrangle Boundary
St. Charles
St. Louis
St. Louis City
Madison
St. Clair
Monroe
Franklin
Jefferson
10 0 10 20 30 40 50 60 70 80 90 Miles
N
S
E
W

# Previous Work

- No previous EQ Loss Estimation for any major metropolitan area in Missouri.
- MAE Center has looked at regional larger interstate network.
- Memphis Study: REDARS (Werner, et al., 2000)
- California: Los Angeles & San Francisco

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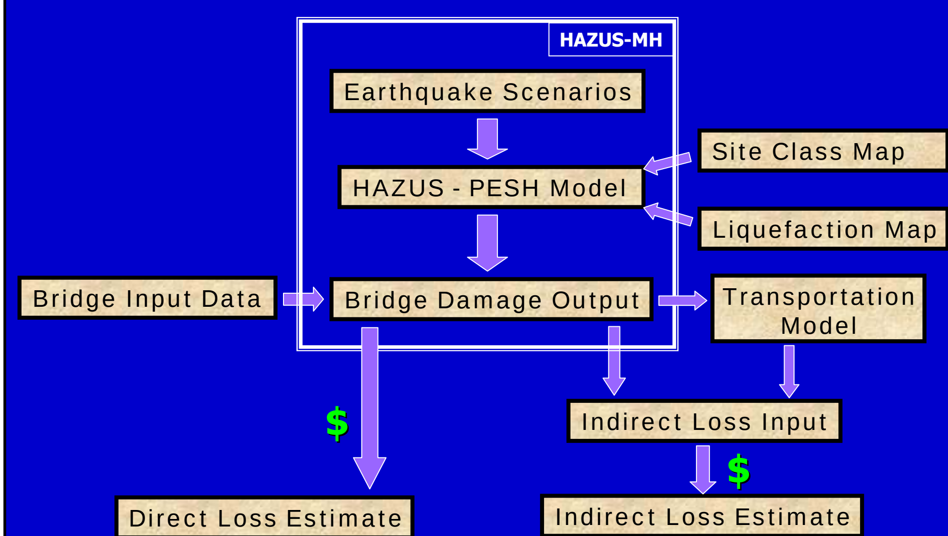
# EQ Loss Estimation Methodology



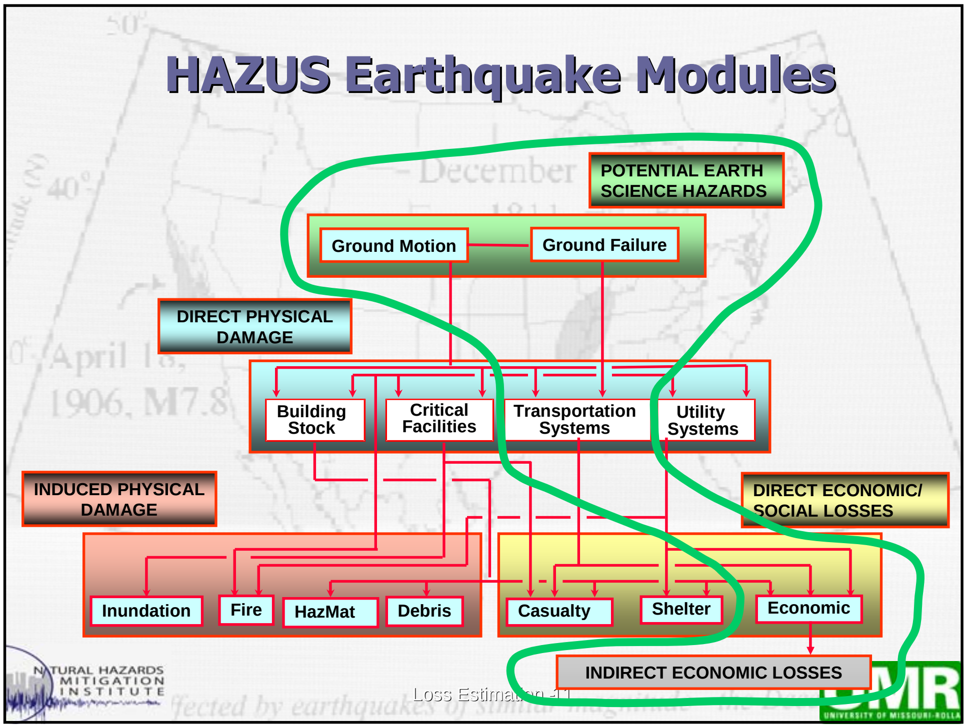
## HAZUS – MH

## Hazards US – Multi-Hazards



## HAZUS-MH

- Software developed by FEMA under a contract with the National Institute of Building Sciences (NIBS) and their contractors.
- GIS driven software that manipulates maps and databases to estimate losses.
- 1997 → 1999 → 2004 (MH)
- Floods, Hurricanes & Earthquakes.


HAZUS Earthquake Modules
POTENTIAL EARTH SCIENCE HAZARDS
Ground Motion
Ground Failure
DIRECT PHYSICAL DAMAGE
Building Stock
Critical Facilities
Transportation Systems
Utility Systems
INDUCED PHYSICAL DAMAGE
DIRECT ECONOMIC/ SOCIAL LOSSES
Inundation
Fire
HazMat
Debris
Casualty
Shelter
Economic
INDIRECT ECONOMIC LOSSES
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Loss Estimation 11
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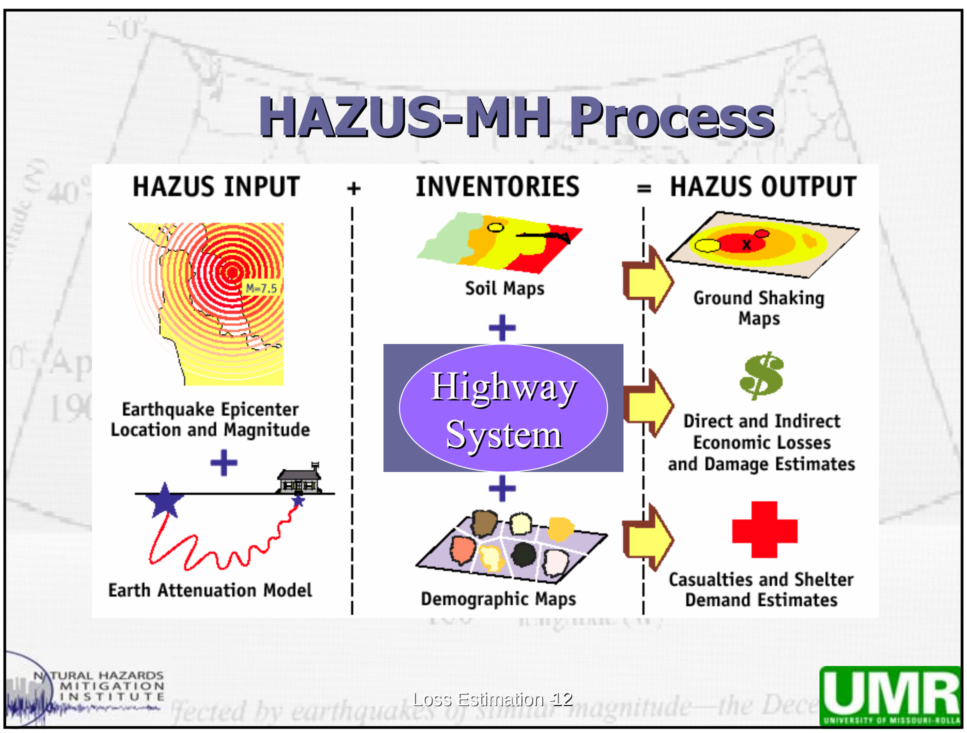
HAZUS-MH Process
HAZUS INPUT
+
INVENTORIES
=
HAZUS OUTPUT
M=7.5
Earthquake Epicenter Location and Magnitude
+
Earth Attenuation Model
Soil Maps
+
Highway System
+
Demographic Maps
Ground Shaking Maps
Direct and Indirect Economic Losses and Damage Estimates
Casualties and Shelter Demand Estimates
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Loss Estimation 12
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# Three Levels of Usage

1. Default Databases: limited use due to site and bridge databases are based on national databases - not much detail data.
2. Modified Databases: to include local site effects and infrastructure, customized databases are used (requires significant user input).
3. Third party model integration to study special conditions.

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# HAZUS-MH in this study

- Deterministic earthquake scenarios.
- PESH model developed distribution of PGA based on 2002 USGS attenuation relationships – database extended to include distances >200mi.
- Losses estimated based on 2002 $ value
- Site class & liquefaction maps developed
- Latest NBI adjusted for local bridges.

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Loss Estimation 14

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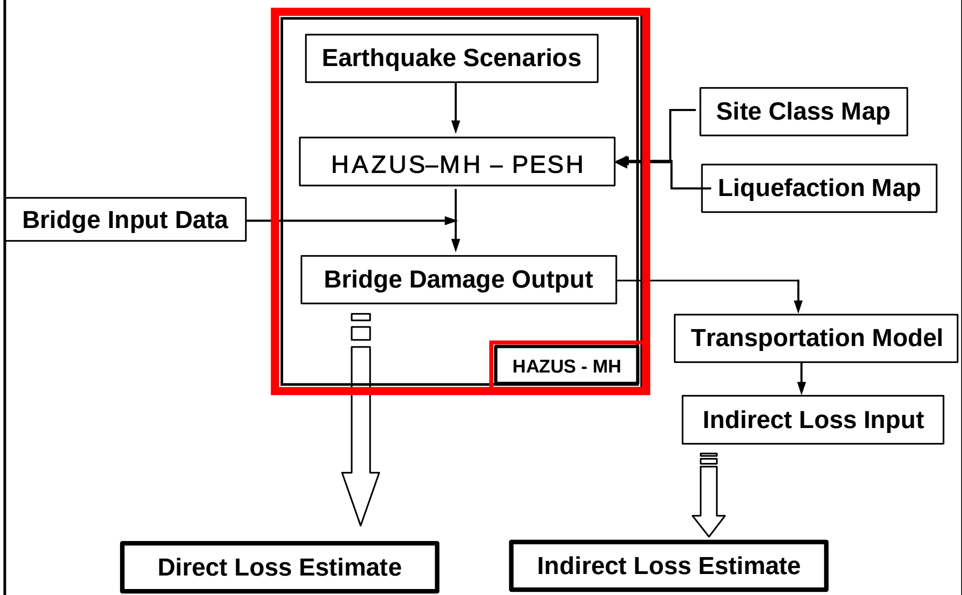
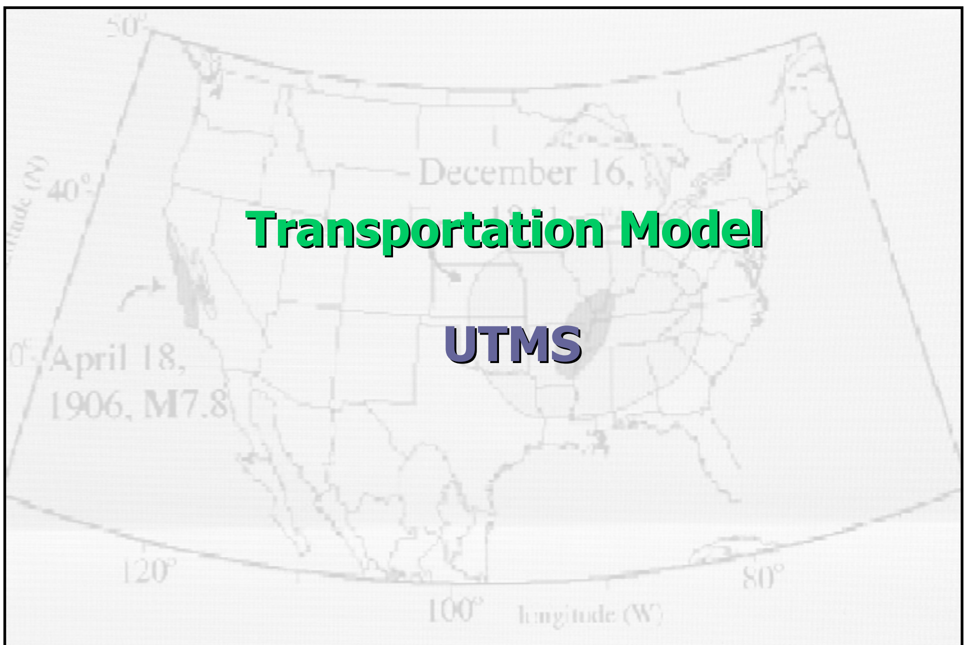
# HAZUS-MH within Study




# Transportation Model

## UTMS

## Transportation Model

- Urban Transportation Modeling System (UTMS) software used for planning.
- East-West Gateway Council (St. Louis) Transportation model – calibrated 2002
- MinUTP: trip generation, distribution and network assignment, given the user prepared link data, zone data, and friction factor data sets .

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Loss Estimation 17

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## Four-step UTMS method

1. People decide to make a trip (generation)
2. Decide where to go (distribution)
3. Decide what mode to take (modal split)
4. Decide what route to use (assignment)

UTMS remains the standard modeling tool for the vast majority of metropolitan areas around the world, a wide variety of commercially available software packages is available to support UTMS-based modeling.

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# Earthquake Scenarios

# for St. Louis, MO



# Earthquake Scenarios

- Initially focused on the far field condition due to recently revised and released USGS National Seismic Hazard Maps (March 6, 2002)
- Most of the 2002 changes were for short period bridges near the 0.2 sec, not much change for longer period near 1 sec.
- Deterministic, historic, prehistoric and probabilistic methods used.
- Focused on geologic evidence worst case scenario.

## Earthquake Scenarios - Missouri & Illinois

| Name of EQ Source Zone | Source Zone Fault or Structure | Dist. From STL (miles) | M | Evidence for EQ source | Most recent EQ. (yrs BP) | Refs. ★ |
|---|---|---|---|---|---|---|
| Arnold, Missouri | Unknown | 18 | 5.2 | Paleo-iquefaction features | < 2750 | A, B, C |
| **Germantown, Illinois** | **Unknown** | **38** | **7.0** | **Paleo-liquefaction features** | **< 6,500** | **A, C** |
| Centralia, Illinois | Unknown - | 56 | 7.5 | Paleo-liquefaction features | < 6,500 | A, C, D |
| Vincinnes, Indiana | Wabash Valley fault zone | 146 | 7.5 | Paleo-liquefaction features | 6,100 | C, E, F |
| **New Madrid, Missouri** | **New Madrid seismic zone** | **148** | **7.7** | **Historic earthquakes and paleo-liquefaction features** | **107** | **C, G** |
| **St. Louis, Missouri** | **USGS background seismicity** | **0** | **7.0** | **None - assumed possible anywhere in the Central U.S. inboard "craton" zone** | **Unknown** | **G** |

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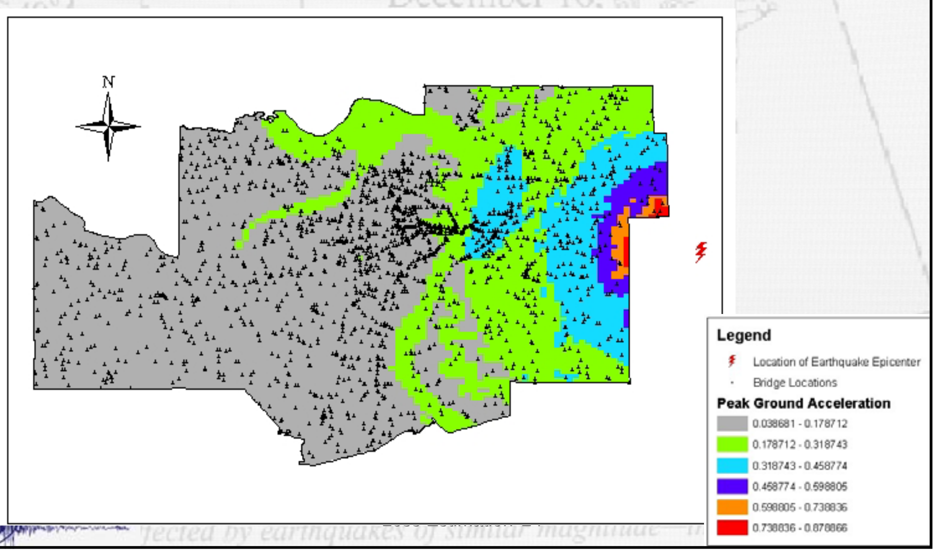
# Summary of EQ Input Parameters

| Name Earthquake Scenario | Lat. (d,d) | Long. (d,d) | $M_m$ | Epicenter Depth (km) | Attenuation Relationship |
|---|---|---|---|---|---|
| 1. St. Louis, MO | 38.63 | -90.2 | 7.0 | 10 | Project 2000 East |
| 2. Germantown, IL | 38.56 | -89.5 | 7.0 | 10 | Project 2000 East |
| 3. New Madrid, MO | 36.55 | -89.54 | 7.7 | 10 | Frankel (1996) |



# PGA – Germantown EQ with bridge inventory



## Site Class – GMA

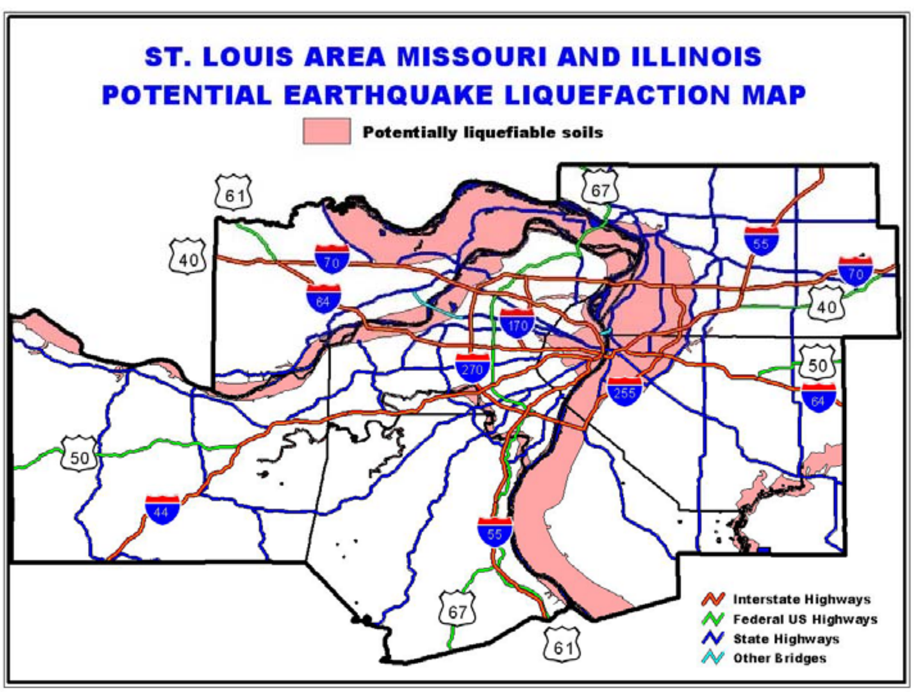
- Ground Motion Amplification (GMA)
  - simplified site response factors based on amplification factors - NEHRP 1997.
- GIS maps were based on data from MoDNR and IGS for this purpose.
- USGS NEHRP is in the process to develop new maps for St. Louis including site specific data (available from geotechnical community and research projects).



# Liquefaction distribution

- A separate liquefaction potential map for Missouri and Illinois was prepared for use in a GIS HAZUS environment.
- A lateral spreading potential map was prepared as an area around the river channels, but areas are too small to be seen at a map scale suitable for page size.





# Bridge Inventories

- Major highways in the area include Interstates 70, 170, 270, 44, 55, 64 and Highway 67.
- National Bridge Inventory (NBI) produced by the Federal Highway Administration, Office of Bridge Technology.
- State DOT sources



# Major MO/MS Rivers Bridges

| Structure (NBI Item 8) | County (NBI Item 3) | Feature Intersected (NBI Item 6a) | Facility Carried (NBI Item 7) | Year Built (NBI Item 27) | 1999 ADT (NBI Item 29,30) | Structure Length (NBI Item 49, m) |
|---|---|---|---|---|---|---|
| A40171 2 | St. Charles | MISSOURI RIVER | US 40 (E) | 1991 | 39969 | 796.7 |
| A5585 4 | St. Charles | MISSOURI RVR | MO 364 | 1999 | 72400 | 986.9 |
| A4557 2 | St. Charles | MISSOURI RVR | MO 370 (N) | 1992 | 9532 | 1053.1 |
| A4557 3 | St. Charles | MISSOURI RVR | MO 370 (S) | 1993 | 9532 | 1053.1 |
| J10004 3 | St. Charles | MISSOURI RVR | US 40 (W) | 1935 | 39463 | 796.7 |
| A3047 4 | St. Charles | MISSOURI RVR | US 67 | 1979 | 32567 | 848.3 |
| A4278 4 | St. Charles | MISSISSIPPI RVR | US 67 | 1994 | 28565 | 1408.2 |
| A3292R 2 | St. Louis | MISSOURI RIVER | IS 70 (E) | 1978 | 143463 | 1155.8 |
| L05617 3 | St. Louis | MISSOURI RVR | IS 70 (W) | 1958 | 87752 | 1244.5 |
| A1850 3 | St. Louis | MISSISSIPPI RVR | IS 255 (W) | 1985 | 28859 | 1220.1 |
| A4936 2 | St. Louis | MISSISSIPPI RVR | IS 255 | 1990 | 26393 | 1220.1 |
| A 890 4 | St. Louis City | MISSISSIPPI RVR | IS 270 | 1964 | 52299 | 824.8 |
| A4856 1 | St. Louis City | MISSISSIPPI RVR | MO 770 | 1900 | 41076 | 1222.2 |
| A1500R3 4 | St. Louis City | MISSISSIPPI RVR | IS 70 | 1963 | 149848 | 659.9 |
| K09691 1 | Franklin | MISSOURI RVR | MO 47 | 1934 | 8811 | 780.9 |

(Source: 2001 NBI by FHWA)

# Multiple Bridge databases

| Bridge Inventory | Media | Date Updated | Inventory Items |
|---|---|---|---|
| MoDOT GIS | GIS | 2001 | 45 |
| MoDOT District 6 (1) | Database | 1999 | 6 |
| MoDOT District 6 (2) | Database | 2002 | 6 |
| Illinois ISIS/SIMS | GIS/Database | 2003 | 170 |
| FEMA's HAZUS-MH | GIS/Database | 2001 | 25 |
| FHWA's NBI | GIS/Database | 2002 | 116 |



# Multiple Bridge databases

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| **FEMA's HAZUS-MH** | **GIS/Database** | **2001** | **25** |
| FHWA's NBI | GIS/Database | 2002 | 116 |

# HAZUS-MH and NBI

- HAZUS-MH Release 28-D incorporates:
  - 2,645 bridges
  - 771 road segments
- into its database for the region of study selected for this project.
- 28 Bridge classes.
- 2001 NBI data set.



# Items in HAZUS-MH bridge inventory

**(Adapted from FEMA Metadata for HAZUS-MH Release 28-D.)**

| Item Name | Description |
|---|---|
| Highway Bridge Id | HAZUS-MH Internal ID |
| Bridge Class | Analysis Class |
| Tract | Census Tract |
| Name | Bridge Name |
| Owner | Bridge Owner |
| Bridge Type | Structure Type |
| Width | Bridge Width (m) |
| Number of Spans | Number of Spans |
| Length | Total Bridge Length (m) |
| Max Span Length | Maximum Span Length (m) |
| Skew Angle | Skew Angle (degrees) |
| Seat Length | Seat Length (m) |
| Seat Width | Seat Width (m) |

| Item Name | Description |
|---|---|
| Year Built | Year Bridge Was Built |
| Year Remodeled | Year Bridge Remodeled |
| Pier Type | Pier Type |
| Foundation Type | Foundation Type |
| Scour Index | Scour Index |
| Traffic | Daily Traffic (cars/day) |
| Traffic Index | Traffic Index |
| Condition | General Condition Rating |
| Cost | Replacement Cost (thous. $) |
| Latitude | Latitude of Bridge |
| Longitude | Longitude of Bridge |
| Comment | Misc. Comments |

# Direct Losses



# Direct Losses

The cost to repair a bridge back to 100% capacity after incurring damage due to an earthquake event.

"Direct economic losses are computed based on:

(1) probabilities of being in a certain damage state,

(2) the replacement value of the component, and

(3) damage ratios for each damage state.

Economic losses are evaluated by multiplying the compounded damage ratio by the replacement value, where the compounded damage ratio is computed as the probabilistic combination of damage ratios." [HAZUS-MH (2002) Technical Manual, Pg. 15-31]

# Number of Bridges Damaged St. Louis Earthquake, M=7.0

| Probability of Occurrence | Initial Damage State | | | | |
|---|---|---|---|---|---|
| | Complete | Exceed Extensive | Exceed Moderate | Exceed Slight | None |
| =1.0 | 0 | 0 | 0 | 0 | 81 |
| ≥0.75 | 29 | 163 | 216 | 367 | 1448 |
| ≥0.50 | 188 | 469 | 564 | 732 | 1913 |
| ≥0.25 | 521 | 836 | 997 | 1197 | 2278 |
| >0 | 2216 | 2423 | 2480 | 2564 | 2645 |
| ≥0 | 2645 | 2645 | 2645 | 2645 | 2645 |

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# Number of Bridges Damaged Germantown Earthquake, M=7.0

| Probabability of Occurrence | Initial Damage State | | | | |
|---|---|---|---|---|---|
| | Complete | Exceed Extensive | Exceed Moderate | Exceed Slight | None |
| =1.0 | 0 | 0 | 0 | 0 | 81 |
| ≥0.75 | 0 | 0 | 2 | 232 | 2427 |
| ≥0.50 | 0 | 9 | 50 | 103 | 2542 |
| ≥0.25 | 9 | 112 | 155 | 218 | 2613 |
| >0 | 1483 | 1999 | 2146 | 2239 | 2645 |
| ≥0 | 2645 | 2645 | 2645 | 2645 | 2645 |

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## Number of Bridges Damaged New Madrid Earthquake, M=7.7

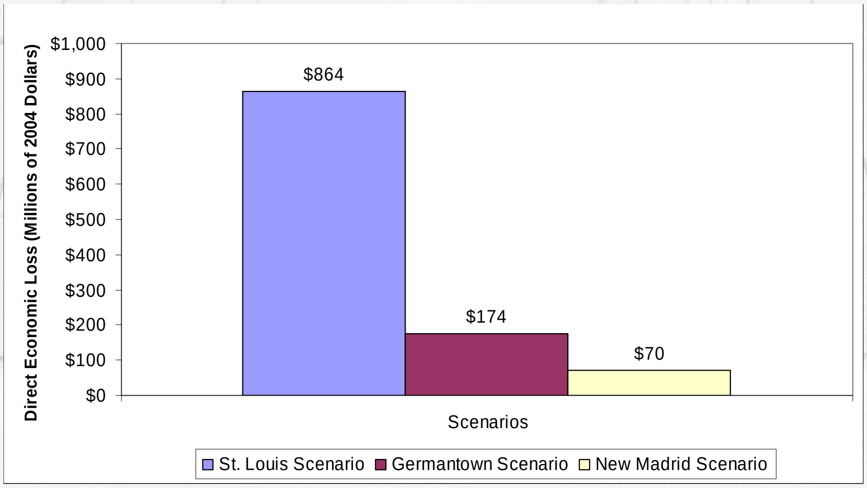
| Probability of Occurrence | Initial Damage State | | | | |
|---|---|---|---|---|---|
| | Complete | Exceed Extensive | Exceed Moderate | Exceed Slight | None |
| =1.0 | 0 | 0 | 0 | 0 | 13 |
| ≥0.75 | 0 | 0 | 0 | 0 | 2494 |
| ≥0.50 | 0 | 0 | 5 | 58 | 2587 |
| ≥0.25 | 0 | 29 | 67 | 151 | 2645 |
| >0 | 1738 | 2306 | 2471 | 2632 | 2645 |
| ≥0 | 2645 | 2645 | 2645 | 2645 | 2645 |



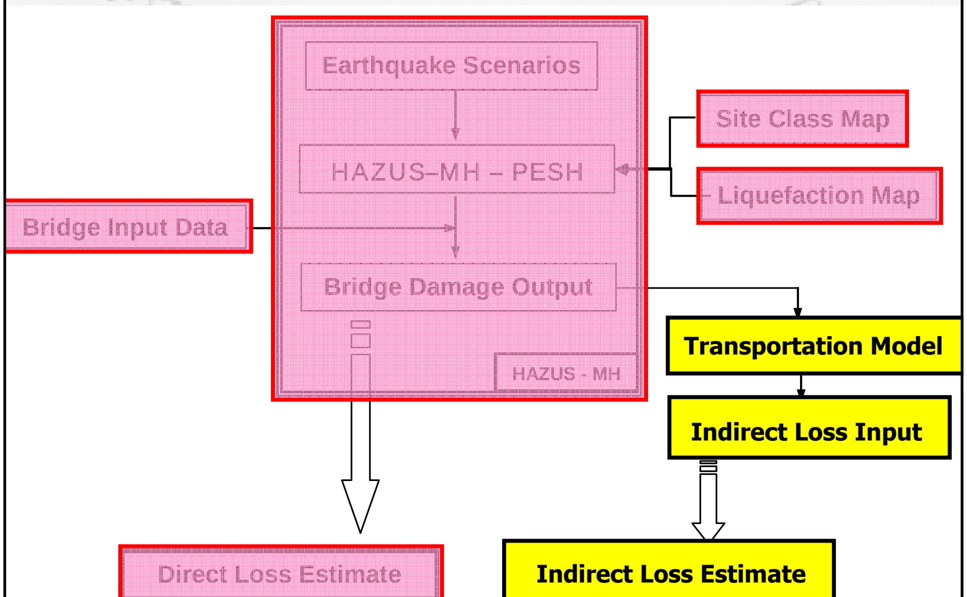
## Replacement Value for Bridges

| System | Replacement Value ($ thousands) | Label | Component Classification |
|---|---|---|---|
| Highway | 20,000 | HWB1 / HWB2 | Major Bridges |
| | 5,000 | HWB8, 9, 10, 11, 15, 16, 20, 21, 22, 23, 26, 27 | Continuous Bridges |
| | 1,000 | HWB3, 4, 5, 6, 7, 12, 13, 14, 17, 18, 19, 24, 25, 28 | Other Bridges |

## Direct Economic Loss Estimate for Bridges at select EQ Scenarios





# Transportation Modeling

# St. Louis, MO

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# Transportation Modeling

- EWG provided transportation data, transportation data models, and results (forecasts) for the years of 2000, 2004, and 2010.
- The 2004 calibrated network was modified to represent each earthquake damage scenario.

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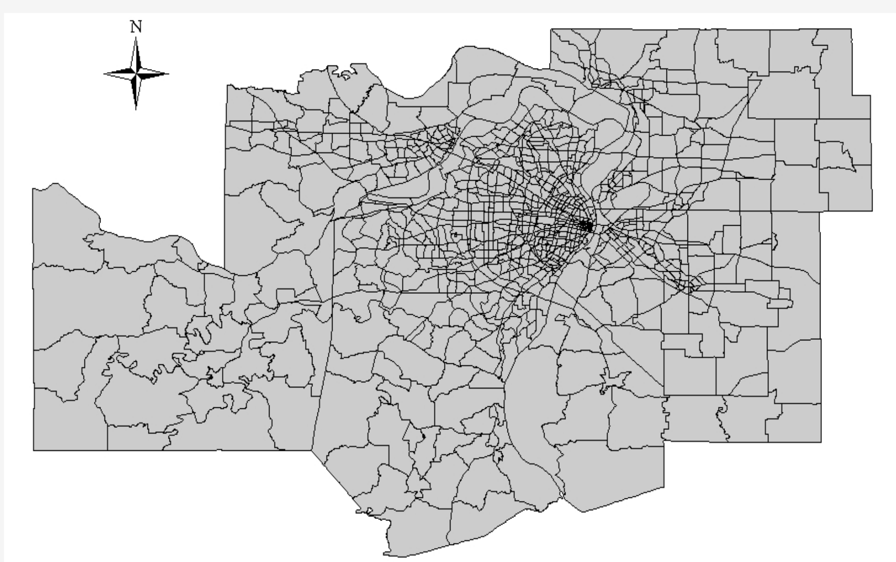
# Loading the Network

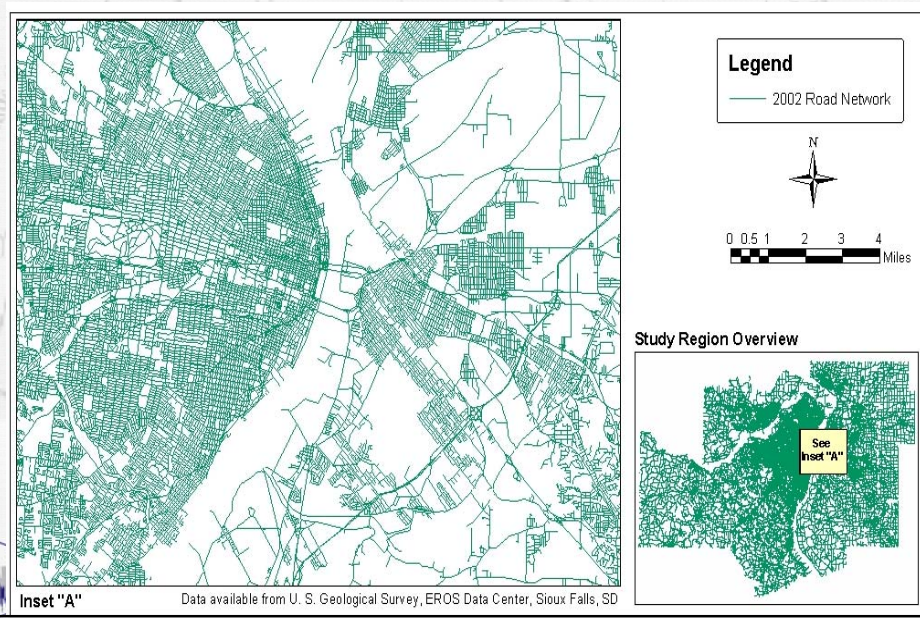
- St. Louis regional travel demand model covers the entire eight-county metropolitan area.
- The metropolitan area is divided in a series of traffic analysis zones (TAZ) with different demographic characteristics.
- The TAZs generate the corresponding travel trips from zone to zone
- These trips load the highway network - in addition to the trips coming into the study area.



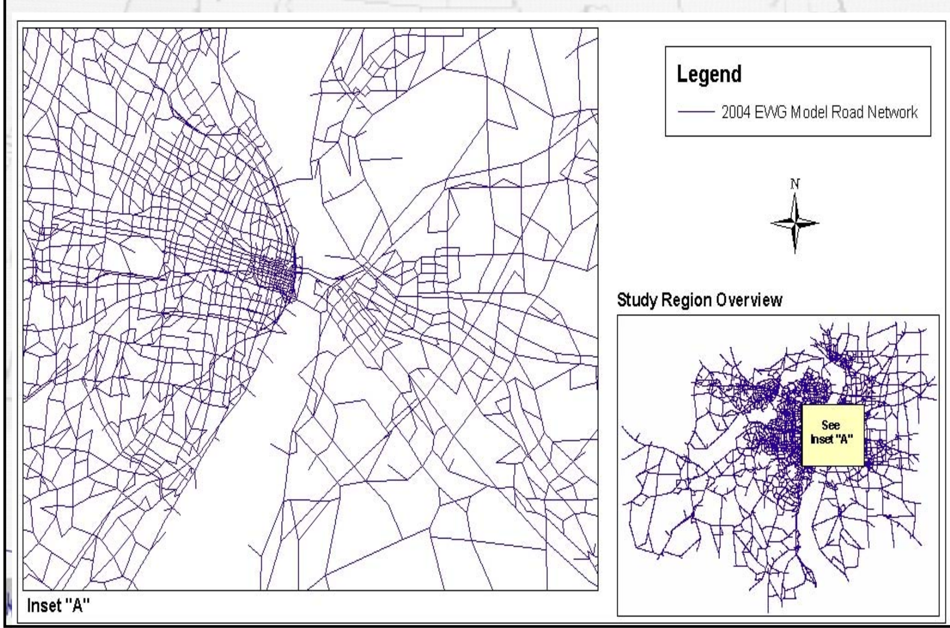
# Transportation Analysis Zones



## The St. Louis Road Network




## Network Model (link-nodes)



# Transitions from HAZUS

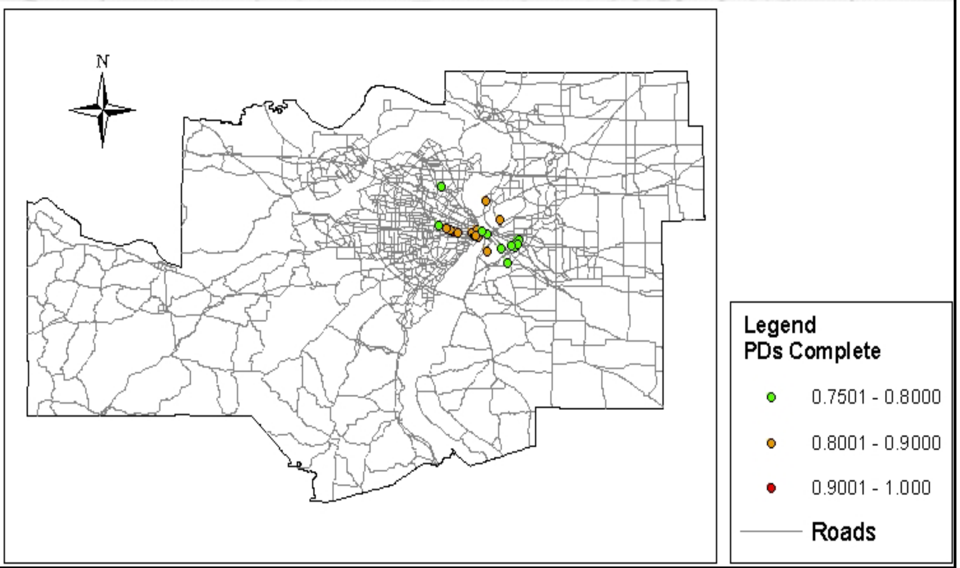
1. HAZUS-MH output data interpretation,
2. Data preparation,
3. Model implementation and runs,
4. Output interpretation.



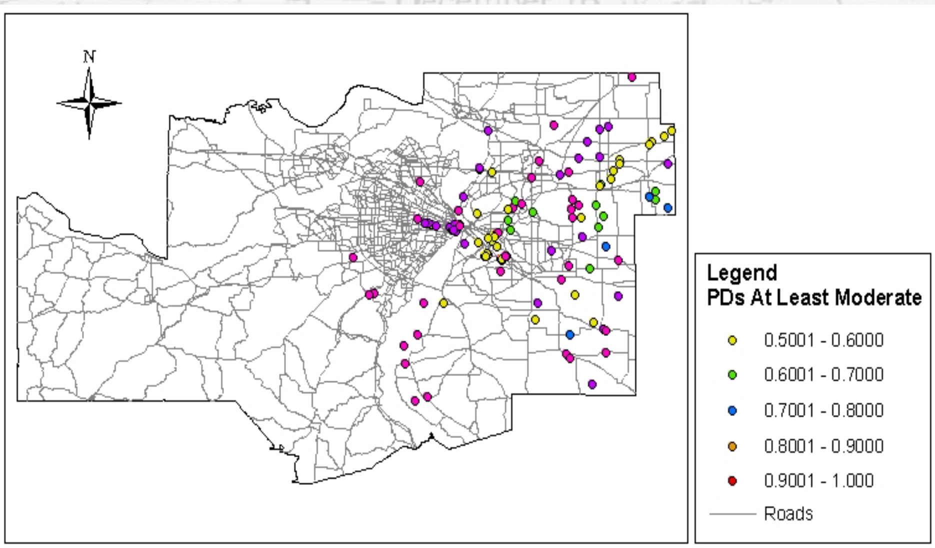
## Model Link Removal

| Scenario (2004) | @ Time (days) | No. Bridges from HAZUS 99/MH Output | No. Bridges Selected for EWG Runs | No. Links on EWG Model Altered |
|---|---|---|---|---|
| New Madrid | 1 | 60 | 32 | 33 |
| New Madrid | 30 | 60 | 32 | 33 |
| New Madrid | 90 | 60 | 32 | 33 |
| New Madrid | 250 | 60 | 32 | 33 |
| Germantown | 1 | 50 | 17 | 19 |
| Germantown | 30 | 50 | 17 | 19 |
| Germantown | 90 | 50 | 17 | 19 |
| Germantown | 250 | 50 | 17 | 19 |
| Germantown | 400 | 50 | 17 | 19 |
| St. Louis | 1 | 29 | 23 | 19 |
| St. Louis | 30 | 29 | 23 | 19 |
| St. Louis | 90 | 29 | 23 | 19 |
| St. Louis | 250 | 29 | 23 | 19 |
| St. Louis | 350 | 29 | 23 | 19 |
| St. Louis | 400 | 29 | 23 | 19 |

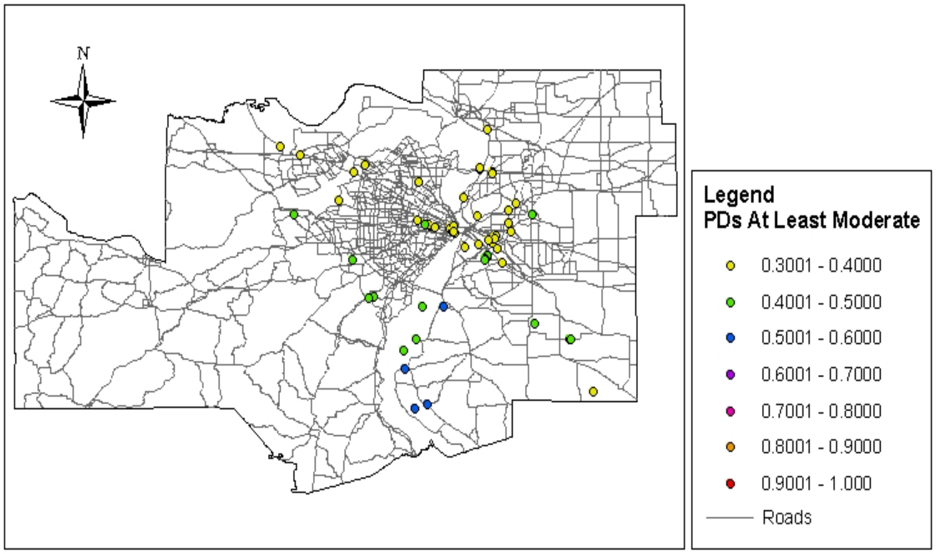
## Probability of Complete Damage ≥ 75% for a St. Louis M 7.0



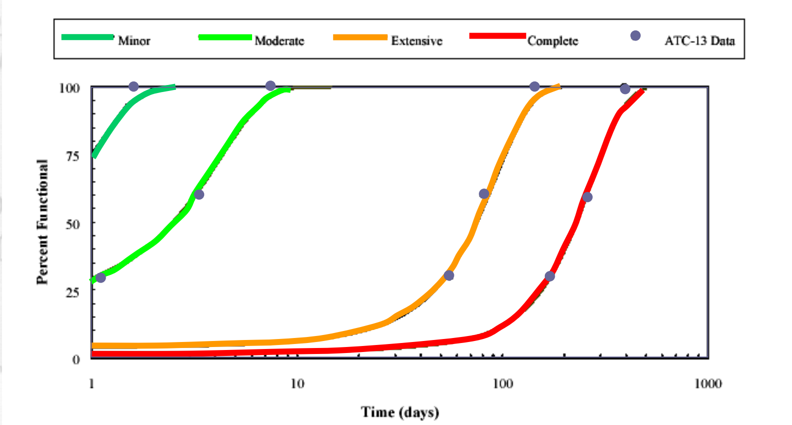

## Probability of Moderate Damage ≥ 50% for a Germantown M 7.0



## Probability of Moderate Damage ≥ 30% for a New Madrid M 7.7




## How HAZUS defines functionality




After ATC 13 (1985)

# Model Runs at EW-Gateway

Idealistic Approach and with all the time in the world... we could do the following runs:

| Earthquake Data | | | Functionality Approach - Reduced Capacities, Never Closed | | | |
|---|---|---|---|---|---|---|
| Scenario | Source | M | Functionality Curve (Multi-Point e.g. after 1,3,7,30,90,250 days) | Functionality Curve (4-Point e.g. after 1, 30, 90, 250 days) | Functionality Curve (2-Point e.g. after 1, 30 days) | Functionality Curve (1-Pt, 1 days) |
| 1 | St. Louis, MO | 7.0 | [redacted] | 4 | [redacted] | [redacted] |
| [redacted] | | | | [redacted] | | |
| 3 | Germantown, IL | 7.0 | | 4 | | |
| [redacted] | | | | [redacted] | | |
| 6 | New Madrid, MO | 7.7 | | 4 | | |
| | TOTAL NUMBER OF RUNS: | | | 24 | | |
| | TOTAL NUMBER OF EWGateway Meetings: | | | 12 | | |



# Model Runs at EW-Gateway

- St. Louis Earthquake (M=7.0 & Dist=0 miles):
  - Removed bridges with P>0.75 (Day 0)
  - Modified bridge capacity according to HAZUS output using restoration curves (Day 30, 90 and 250).
- Germantown Earthquake (M=7.0 & Dist=38 miles)
  - Modified bridge capacity according to HAZUS output using restoration curves (Day 30, 90 and 250).
- New Madrid Earthquake (M=7.7 & Dist=148 miles)
  - Level of earthquake is too far away to cause damage in St. Louis. Attenuation functions in HAZUS control the results. The number of bridges affected is small.

# Indirect Losses



# Analysis for Indirect Loss

- For each of the three scenarios, the MINUTP runs were created for days 1, 30, 90, and 250.
- The St. Louis and Germantown scenarios also included runs for day 350 and 400. These were not completed for the New Madrid run due to insignificant findings from the other 2 events at these times following the earthquake event.

## Analysis for Indirect Loss

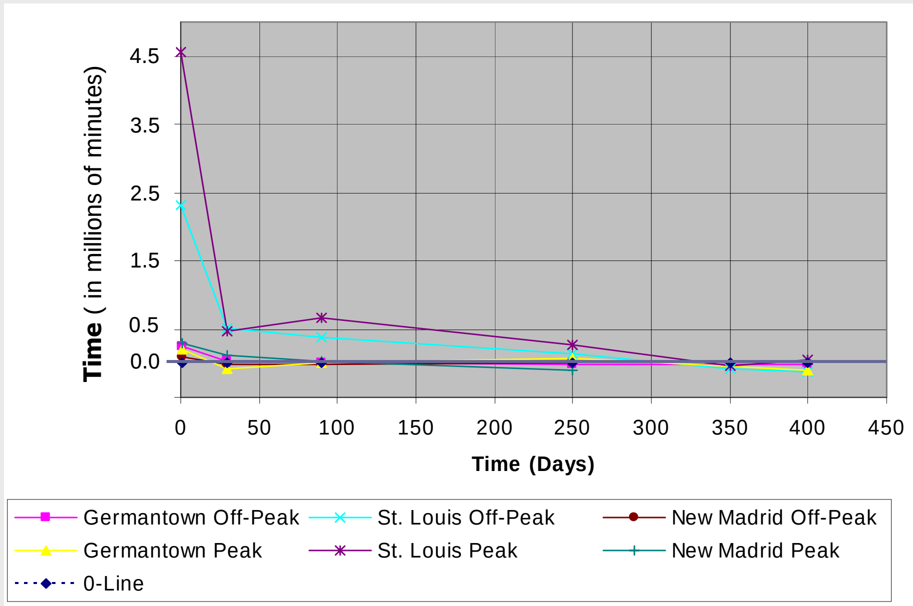
- The St. Louis run was created with day "1" links being completely removed from the EWG network, simulating the bridges being closed immediately following the earthquake event which is appropriate for bridges in the "complete" damage state.
- The runs for the Germantown and New Madrid earthquake events were made with day "1" links being reduced, but not removed, in order to simulate a reduced capacity while the bridge was still able to be used. This was more appropriate for the lesser damage states initially selected for the bridge selection in these events



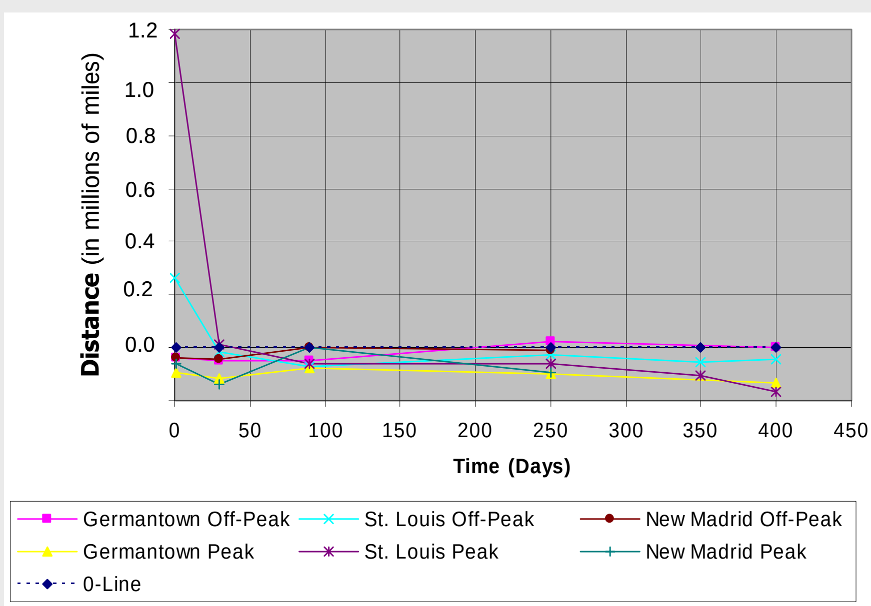
## Travel Time & Distance

- Another preparation for indirect loss estimates is the travel time delays and increased distance traveled by the public.
- This is computed in a matrix of all the trips generated by the network.
- The change in time and distance traveled is shown in the following charts.

## Peak & Off-Peak Change in Travel Time




## Peak & Off-Peak Change in Travel Distance



## Indirect Losses - definition

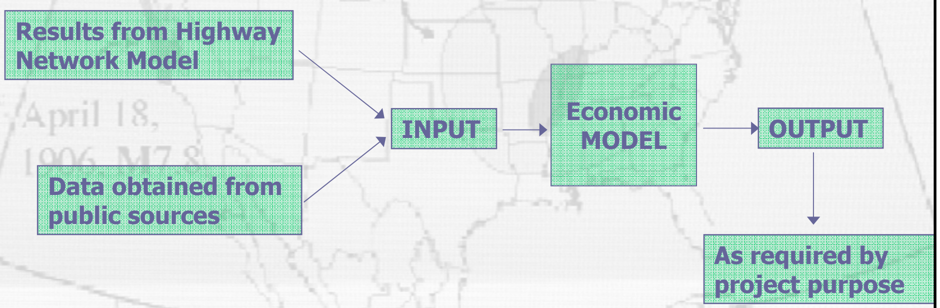
Indirect economic loss will normally cover the economic loss to items not included in the normal restoration costs. Damage of the transportation network will incur an increase of transportation costs, lower productivity, among others. It is practically impossible to capture every indirect loss resulting from an earthquake by a single economic model.



## Indirect Losses - definition

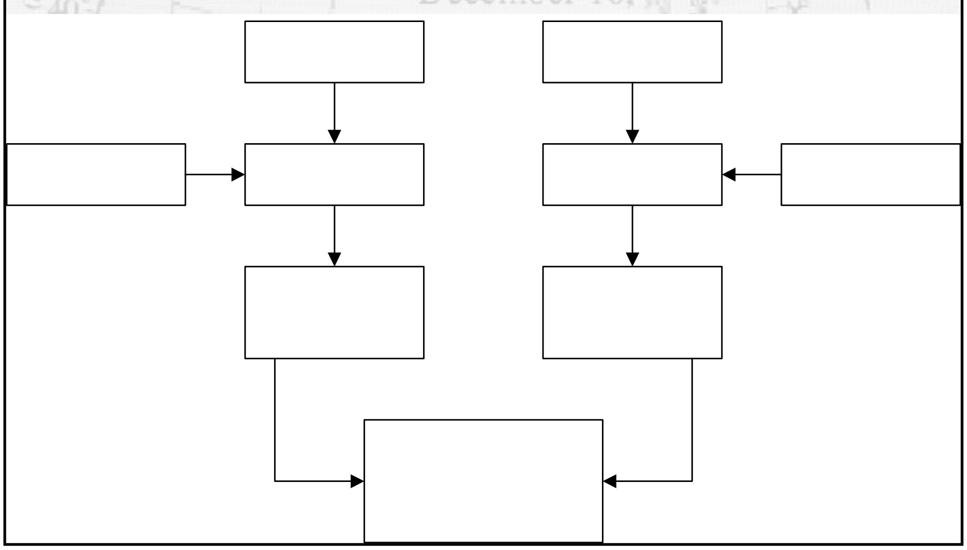
The indirect economic loss of this project is labeled as "Partial Indirect Economic Loss: The Impact on Highways for the Traveling Public". The definition of this partial indirect loss is defined as the expected financial loss that occurs from increases in transportation costs in the highway network.

## Economic Model – indirect loss






## Indirect Loss Economic Framework



# Formulation

$$\text{Total Partial Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} \text{Loss from increase travel time of route ij} +$$

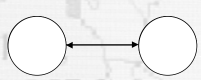
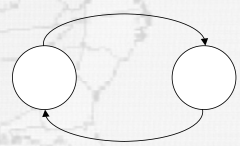
$$\sum_{i=1}^{n}\sum_{j=1}^{n} \text{Loss from increase travel distance of route ij}$$

where:
- i = Route origin zone number
- j = Route destination zone number
- n = Total number of zones in the study area



# Commuting Trips

- Demographics will affect the value of the trips and are weighted accordingly.

| | | |
|---|---|---|
|  |  |  |
| Trip of person in zone A from zone A to zone B | Trip of person in zone B from zone B to zone A | Trip of person in zone A from zone A to zone B and then his/her return trip from zone B to A |

# Commercial Trips

- Those made by commercial freight.
- Divided into two categories:
  1. Trucks
  2. Tractor + Trailer

| | Tractor & Trailer | Truck | Weighted |
|---|---|---|---|
| Value of Time Delayed (per hour) | $29.86 | $26.97 | $29.06 |
| Value of Increased Distance (per km) | $0.76 | $0.52 | $0.70 |

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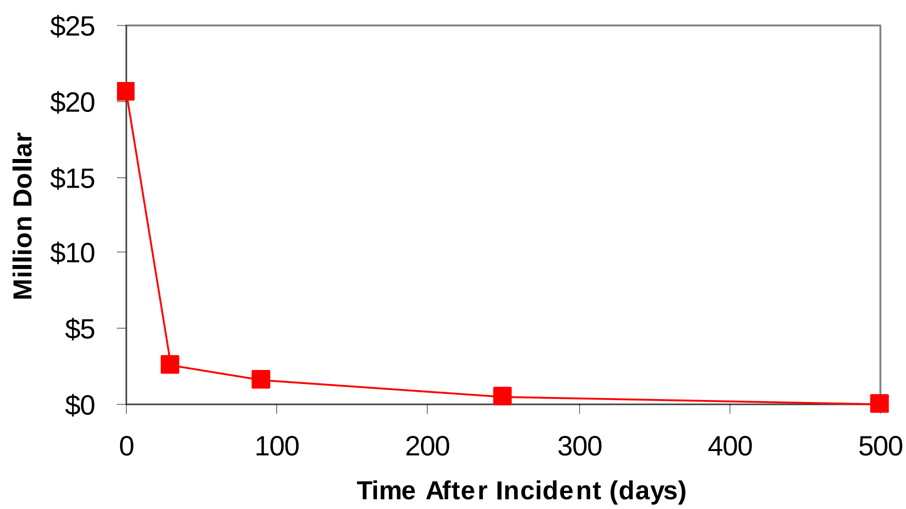
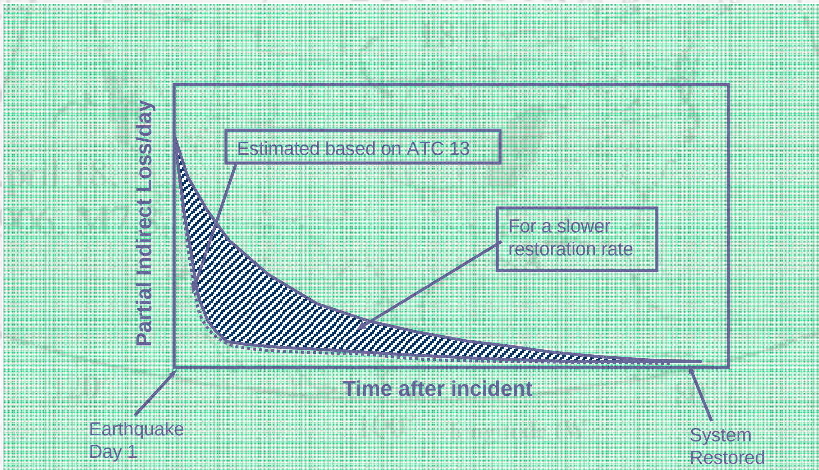
## St. Louis Daily Partial Indirect Loss Estimation



# Partial Indirect Loss for Different Restoration Rate






# Summary & Conclusions

- The original objective to demonstrate that a loss estimate can be made for the St. Louis area was accomplished.
- Both direct and indirect losses have been calculated for select earthquake scenarios, including one in the NMSZ.

## Summary & Conclusions (continued)

- HAZUS combined with transportation models can be used for earthquake loss estimation.
- Process is complex and tedious – a more streamlined software systems would ease this process, e.g., REDARS.
- Earthquake scenarios besides the NMSZ were considered for the St. Louis area.

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Loss Estimation 73

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## Summary & Conclusions (continued)

- The geologic and soil conditions in St. Louis metro area contribute to the variability in ground motion.
- Large areas of liquefaction susceptibility increase the consequences for bridge damage.
- Most of the anticipated damage is on river crossings, old structures and on the Illinois side.

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Loss Estimation 74

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## Summary & Conclusions (continued)

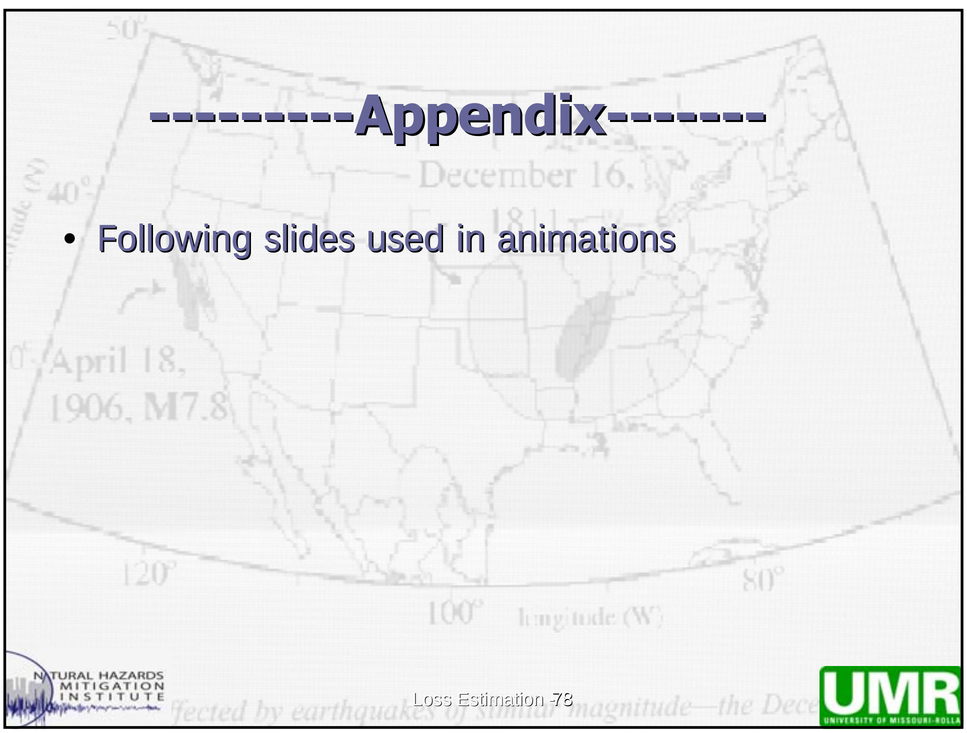
- Direct losses range from $70 to $800 million, depending on EQ scenario.
- Travel time delays and distance can be used to estimate a partial indirect loss.
- Partial indirect losses vary depending on the ability to restore the highway system– starting at $20 million/day at Day 1 and decreasing depending on the ability to restore transportation capacity.



## Summary & Conclusions (continued)

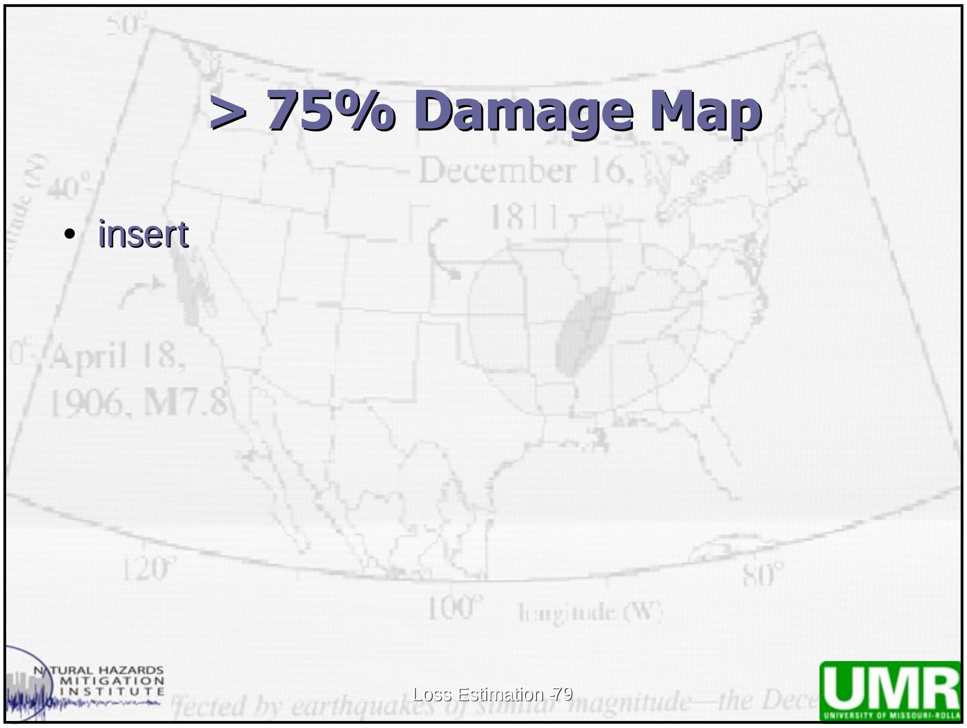
- Partial indirect losses over the entire period of highway network restoration could be $700 million, or higher depending on the ability to restore the transportation highway network.


Thank You!
Questions/Comments
The End
April 18, 1906, M7.8
Loss Estimation -77


---------Appendix-------
• Following slides used in animations
December 16, 1811
April 18, 1906, M7.8
Loss Estimation -78

# > 75% Damage Map

- insert

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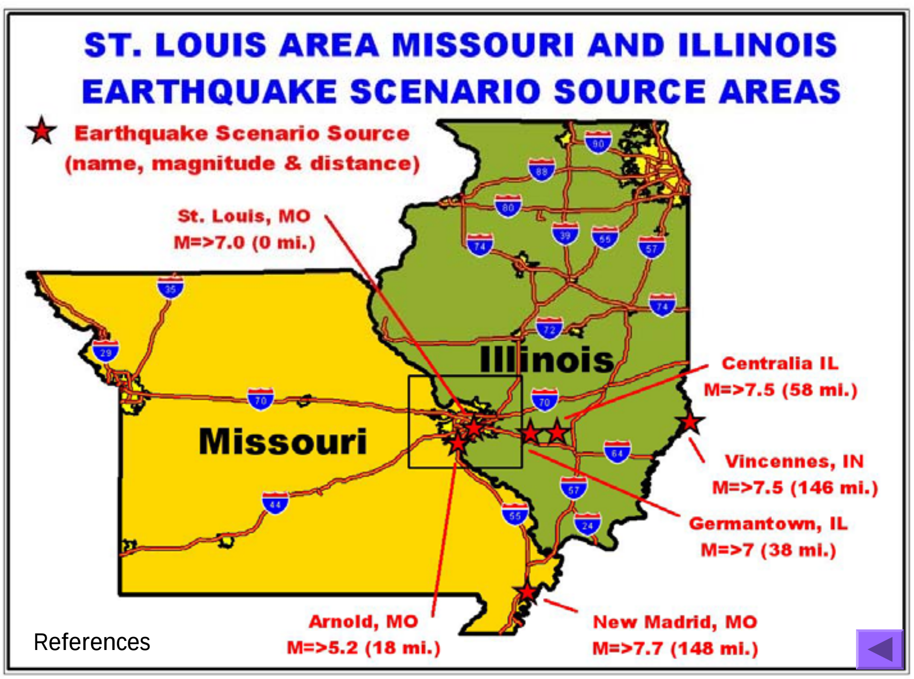

# Earthquake Scenarios
# Missouri & Illinois

| Name of EQ Source Zone | Source Zone Fault or Structure | Dist. From STL (miles) | M | Evidence for EQ source | Most recent EQ. (yrs BP) | Refs. ★ |
|---|---|---|---|---|---|---|
| Arnold, Missouri | Unknown | 18 | 5.2 | Paleo-iquefaction features | < 2750 | A, B, C |
| Germantown, Illinois | Unknown | 38 | 7.0 | Paleo-liquefaction features | < 6,500 | A, C |
| Centralia, Illinois | Unknown - | 56 | 7.5 | Paleo-liquefaction features | < 6,500 | A, C, D |
| Vincinnes, Indiana | Wabash Valley fault zone | 146 | 7.5 | Paleo-liquefaction features | 6,100 | C, E, F |
| New Madrid, Missouri | New Madrid seismic zone | 148 | 7.7 | Historic earthquakes and paleo-liquefaction features | 107 | C, G |
| St. Louis, Missouri | USGS background seismicity | 0 | 7.0 | None - assumed possible anywhere in the Central U.S. inboard "craton" zone | Unknown | G |

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# References:


A. Tuttle, M., Chester, J., Lafferty, R., Dyer-Williams, K., and Cande, R., 1999, Paleoseismology Study Northwest of the New Madrid Seismic Zone U.S. Nuclear Regulatory Commission, NUREG/CR-5730

B. Tuttle, M. P., 2001 Personal communication

C. Crone, A. J., and Wheeler, R. L., 2002 Data for Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States, east of the Rocky Mountain front U.S. Geological Survey, Open-File Report 00-260. http://pubs.usgs.gov/of/2000/ofr-00-0260/

D. Bauer, R., 2002, Personal communication by the Illinois State Geological Survey

E. Munson, P. J., and Munson, C. A., 1996, Paleoliquefaction Evidence for Recurrent Strong Earthquakes Since 20,000 Years BP in the Wabash Valley Area of Indiana, Report to USGS National Earthquake Hazards Reduction Program, Grant No. 14-08-0001-G2117

F. Martin, J. R., 199X, Seismic Parameters for the Central United States Based on Paleoliquefaction Evidence in the Wabash Valley.

G. Frankel, A. D., Petersen, M. D., Mueller, C. S., Haller, K. M., Wheeler, R. L., Leyendecker, E. V., Wesson, R. L., Harmsen, S. C., Cramer, C. H., Perkins, D. M., and Rukstales, K. S., 2002, Documentation for the 2002 Update of the National Seismic Hazard Maps, U.S. Geological Survey, Open-File Report 02-420 http://geohazards.cr.usgs.gov/eq/of02-420/OFR02-420.pdf


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A. Tuttle, M., Chester, J., Lafferty, R., Dyer-Williams, K., and Cande, R., 1999, Paleoseismology Study Northwest of the New Madrid Seismic Zone U.S. Nuclear Regulatory Commission, NUREG/CR-5730

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G. Frankel, A. D., Petersen, M. D., Mueller, C. S., Haller, K. M., Wheeler, R. L., Leyendecker, E. V., Wesson, R. L., Harmsen, S. C., Cramer, C. H., Perkins, D. M., and Rukstales, K. S., 2002, Documentation for the 2002 Update of the National Seismic Hazard Maps, U.S. Geological Survey, Open-File Report 02-420 http://geohazards.cr.usgs.gov/eq/of02-420/OFR02-420.pdf




# HAZUS - PESH Model

- PESH=Potential Earth Science Hazards
- Ground shaking maps produced
  - Basis for ground shaking (Probabilistic Seismic Hazard Maps (USGS))
  - Standard shape of response spectra
  - Attenuation of ground shaking (CEUS Default-50% Frankel 1996 + 50% Toro 1997)
  - Amplification of ground shaking - local site conditions (site classes and soil amplification factors proposed for the *1997 NEHRP Provisions*)

# Site Class – GMA

- Ground Motion Amplification
  - simplified site response factors based on amplification factors based on NEHRP 1997.
- We have adopted MODNR Surficial deposits MAP for this purpose.
- USGS NEHRP is in the process to develop new maps for St. Louis



# HAZUS - Liquefaction Map

- Inputs
  – A geologic MAP based on the age, depositional environment, and the material characteristics of the geologic units were used to create a liquefaction susceptibility map (Liquefiable - Soil Site Class F)
  – Groundwater depth map is supplied with a default depth of 5 feet.
  – Earthquake Moment Magnitude (**M**)
- Output
  – Aerial map depicting estimated permanent ground deformations

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Loss Estimation 87

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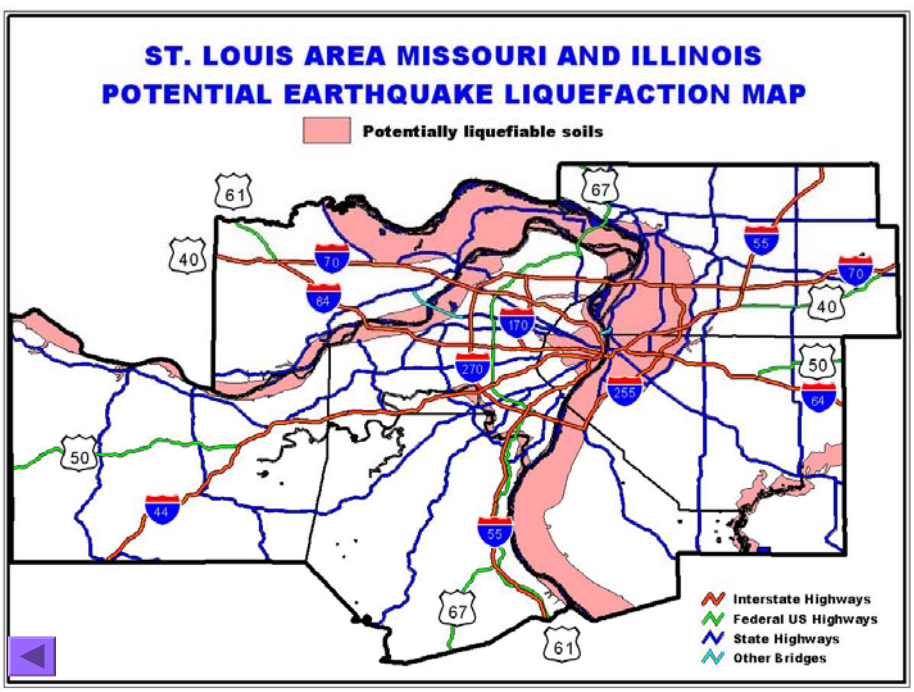


## HAZUS – Bridge Input Data

- Bridges divided into 28 categories based on 1996 NBI database
- Inputs
  - Bridge Classification (based on the following structural characteristics: Seismic Design, Number of spans, Structure type, Pier type, Abutment type and bearing type, Span continuity)
  - Geographical location of bridge (longitude and latitude)
  - Spectral accelerations at 0.3 sec and 1.0 sec, and PGD at bridge (for fragility curves)
  - Peak Ground Acceleration (for PGD-related computations)



## HAZUS – Damage Output

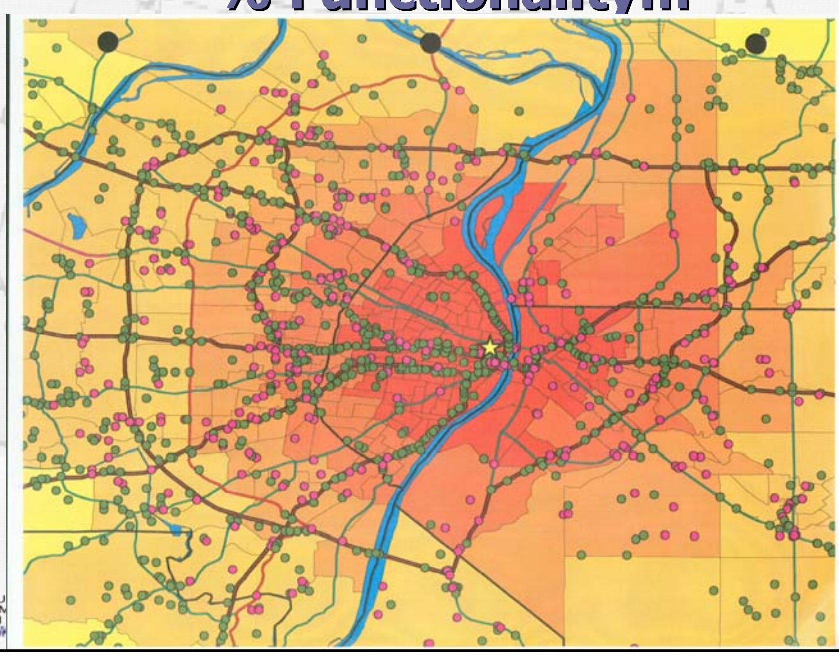
- % Damage
  - Initial damage state only
  - Output is in terms of probability of slight, moderate, extensive, or complete damage to occur for the input earthquake scenario
- % Functionality
  - Damage state over time
  - Output is in terms of % functionality at time periods of 1, 3, 7, 30, and 90 days

# HAZUS – Direct Losses

- Limited to the cost of repairing damage to the lifeline system
- Output in 1994 dollars
- Default values are provided for replacement values of lifeline components as a guide



# % Functionality…



# Indirect Losses - Input

- Calibrated urban transportation planning model (Minutp software from EWG)
  - 2004 baseline selected
  - Census Bureau demographic data from 2000 projected to 2004
  - Current transportation highway system
- Bridges to be removed from the network
  - Selected those from HAZUS runs with
    P (complete damage) > .75



# Indirect Losses - Output

- Cost due to longer travel time
  - Delay =Final travel time – Baseline travel time
  - What is the value of time?
- Cost due to longer travel distance
  - Final travel dist. – Baseline travel dist.
  - Increase in dist. traveled =
    Final dist. – Baseline dist.
  - Cost of longer distance of travel
- Indirect transportation cost =
  Delay cost + Cost of longer travel distance


Thank You!
Questions/Comments
The End
April 18,
1906, M7.8
40°
50°
120°
100°
80°
Loss Estimation 95
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