Economic Impacts of Unscheduled, Disruptive Events

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Mid-America Earthquake Center

Issues and challenges

- Economists have a difficult enough time forecasting equilibrium conditions
- Unexpected events pose greater challenge because of the lack of observations and analytical work
- Prior work is suggestive of what will/might happen – not a forecast
- Focus on climate disruptions and earthquake analysis

Past Experience

- Chicago Flood 1992
  - CRAINS business newspaper headline - $1.5 billion
    - End of the year total - $350-400 m (REAL forecast $200-400 m)
    - Infrastructure - $120 m
- Iowa (Mississippi) Flood
  - GNP at end of 1993 higher than long term forecast
  - Infusion of state and federal relief dollars stimulated a boom in construction activity
  - Negative effects concentrated spatially

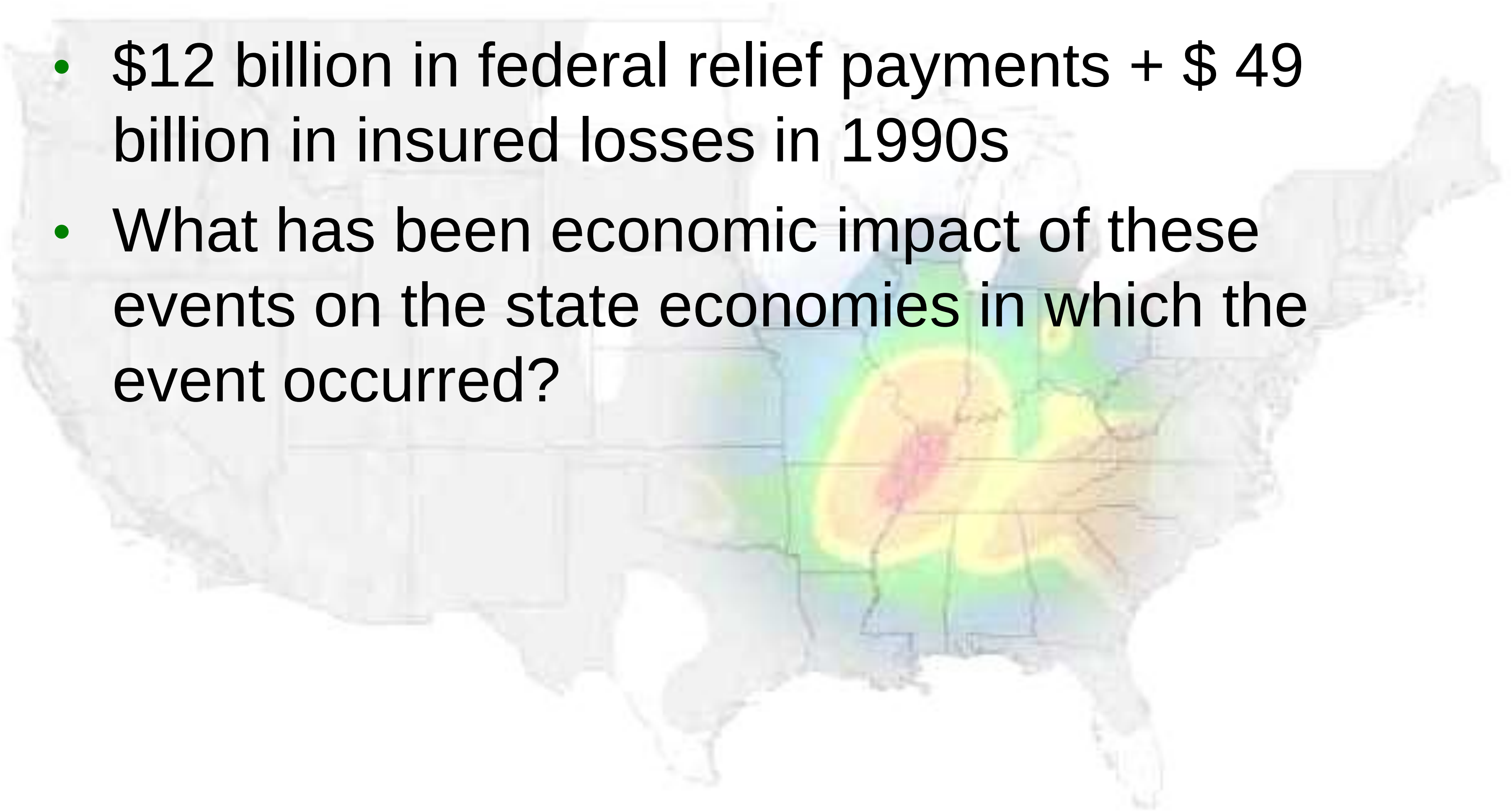
Past Experience

- **Extreme Climatic Events**
  - No discernable impact on annual changes in GSP for sample of states
  - Infusion of federal aid dollars outweighed losses due to climate (tornado, flood, hurricanes)
- Gas Price Impacts (relates to economic security)
  - Redirection of $10/week/household in Chicago from usual array of purchases to gasoline resulted in loss of $1.2 billion in local economy over course of a year

The 1990s Extreme Events

Event	Dates	States Affected	Federal Payments	Date of Payments
Flood	1982-1983	California	$120m	1983
Severe drought	1988-1989			
		Illinois	$870m	1988-1989
		Iowa	$921m	1988-1989
		Nebraska	$523m	1988-1989
Hurricane Hugo	1989			
		North Carolina	$63m	1989
		South Carolina	$389m	1989
			$9m	1990
Hurricane Andrew	1992			
		Florida	$1.6b	1992
			$41m	1994
			$151m	1995
		Louisiana	$148m	1992
			$2m	1993
Midwest floods	1993			
		Illinois	$630m	1993-1994
		Iowa	$1.7b	1993-1994
		Missouri	$1m	1993-1994
Superstorm	January 1993			
		New-York	$55m	1993
Flood	May 1997	North Dakota	$59m	1997
Floods	1996-1997	California	$69m	1996-1997

Intervention Analysis



- $12 billion in federal relief payments + $ 49 billion in insured losses in 1990s
- What has been economic impact of these events on the state economies in which the event occurred?

Intervention Analysis

- **Intervention analysis** seeks to test for a change in the mean of a time series under the null hypothesis that the intervention (in this case, a weather or climate disaster) created no measurable impact on a state's GSP
- Each event recorded losses > $1 billion (Hurricane Andrew > $25 billion)
- Initial test might be to assess the significance of the difference in the means before and after the intervention, but the possibility of serial correlation renders this test inappropriate.

Intervention Analysis

- The time series data set used is the GSP for 1977-1999.
- For all the states, the log of the data series was used instead of the levels and, in order to insure the stationarity of the data series, a first differencing was required.
- The results of the estimations were tested for normality of errors using the Jarque-Bera test and they were found to be normal.

Intervention Analysis: Results

State	Significant (Yes/No)
California	Yes
Florida	No
Illinois	No
Iowa	No
Louisiana	No
Missouri	No
Nebraska	No
New-York	No
North Dakota	No
North Carolina	No
South Carolina	No

Only in California did the intervention analysis reveal significant difference

Note: referees disputed findings since they "knew better" that the events were significant – paper never accepted for publication!

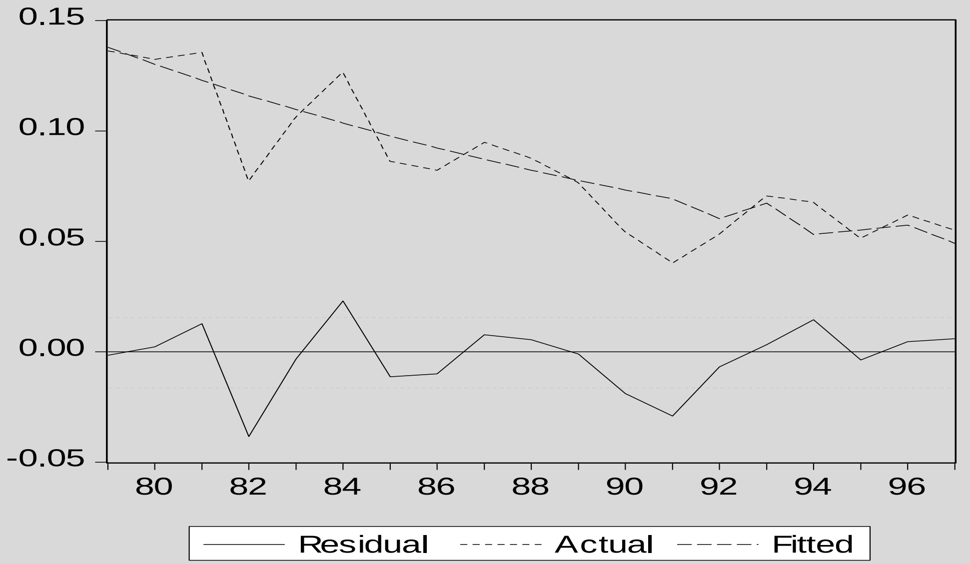
Figure 1: **California**

Dependent Variable: DLOG(CALIFORNIA)
Method: Least Squares
Sample(adjusted): 1979 1997
Included observations: 19 after adjusting endpoints
Convergence achieved after 5 iterations

Variable	Coeff.	Std. Error	t-Statistic	Prob.
C	0.063351	0.017392	3.642536	0.0022
D(CAZ)	-0.019370	0.010209	-1.897399	0.0760
AR(1)	0.700815	0.143847	4.871956	0.0002

R-squared	0.621162	Mean dependent var	0.072157
Adjusted R-squared	0.573807	S.D. dependent var	0.032589
S.E. of regression	0.021275	Akaike info criterion	-4.718598
Sum squared resid	0.007242	Schwarz criterion	-4.569476
Log likelihood	47.82668	F-statistic	13.11719
Durbin-Watson stat	2.139136	Prob(F-statistic)	0.000424
Inverted AR Roots	.70		

Figure 2: **Florida**



Dependent Variable: DLOG(FLORIDA)
Method: Least Squares
Sample(adjusted): 1979 1997
Included observations: 19 after adjusting endpoints
Convergence achieved after 18 iterations
Backcast: 1978

Variable	Coeff.	Std. Error	t-Statistic	Prob.
D(FLZ)	-0.005331	0.007993	-0.667001	0.5143
AR(1)	0.943966	0.008286	113.9270	0.0000
MA(1)	-0.951425	0.085601	-11.11471	0.0000

R-squared	0.760128	Mean dependent var	0.083963
Adjusted R-squared	0.730144	S.D. dependent var	0.030626
S.E. of regression	0.015910	Akaike info criterion	-5.299837
Sum squared resid	0.004050	Schwarz criterion	-5.150715
Log likelihood	53.34845	F-statistic	25.35113
Durbin-Watson stat	1.914934	Prob(F-statistic)	0.000011

Inverted AR Roots	.94
Inverted MA Roots	.95

Interpretation – why no effect?

- Size of payments small in comparison to GSP growth
- Problem of **temporal impact** (over one year, impact + intervention of payments may "neutralize impact)
- For example, after the massive 1993 flood, Illinois' GSP grew from $304 billion to $320 billion between 1993 and 1994. Federal disaster payments of $630 million accounted for less than 4% of the $16 billion growth in the state's GSP between those two years.
- However, in Illinois, if one assumed that the annual growth occurred evenly each quarter and that the flood disrupted activity for one quarter, then federal payments assume a much greater role – over 15% of a quarter's GSP growth.
- Problem of **geographical scale** – county impact >> state impact

Project Aims and Objectives: Network Analysis

- Goal 1

  To develop a set of tools to evaluate the cost-benefit trade-off of pre- or post-earthquake investments designed to reduce direct and indirect earthquake losses.

  - √ Link Interregional Commodity Flow Model (ICFM) with Econometric Input-Output Model
  - √ Estimate Final Demand Loss Model
  - √ Model for Direct and Indirect Earthquake Loss Estimation
  - √ Scenario Analysis Tool

Project Aims and Objectives

- Goal 2

Estimate economic losses due to network damage, taking into account time sequencing and different, but a flexible spatial configuration.

√ Quarterly model developed and linked with transportation network model (based on Okuyama's work for Great Hanshin Earthquake)

√ Continuous time model (to match economic and energy models, since the latter is continuous)

√ Exploring use of GIS to develop flexible spatial configuration

Project Scope

- The scope of the project included development of the framework to calibrate the cost induced by disruption of transportation networks due to earthquakes.
- For the analysis, a 25-year span of the final demands for 83 earthquake analysis zones and for 13 economic sectors are to be estimated.
- The cost approach incorporates several sub-modules.

Project Scope

- In the event of the earthquake:
  - transportation network loss functions by network and by zone were run to obtain the network disruption ratio.
  - The estimated results of the transportation network loss function were entered into the final demand loss function to obtain reduced final demand as well as into the integrated commodity flow model to obtain increased transportation cost.

- The 1812 New Madrid earthquake is used as the basic scenario in the analysis: 200 year recurrence (i.e. 2012…..)
- Most severe earthquake recorded in US
- Stochastic models are combined and GIS integration used in the analysis.

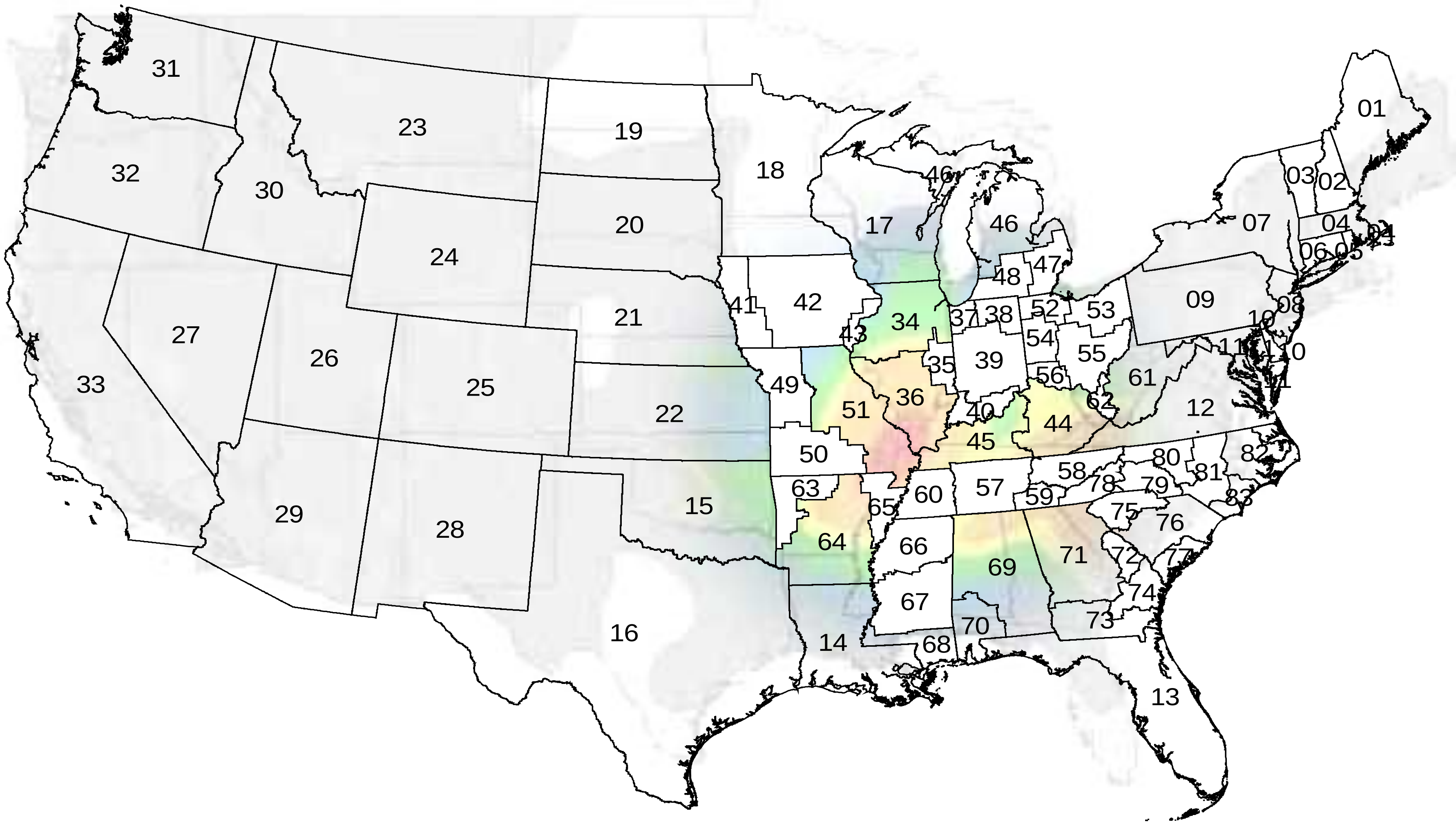
Project Methodology - 1

- Spatial configuration
  - 83 Earthquake Analysis Zone (EQAZ)
  - Existing interstate highway network
  - Existing heavy-traffic railway network
- Temporal configuration
  - Increased flexibility – moved from 1 year to ¼ year (3 months)
  - Explored also continuous time version

EQAZ configuration

- Mid America (50 EQAZ) + RUS (33 states; 33 EQAZ) = 83 EQAZ
- Redefine the Mid America (MA) region (50 EQAZ)
  - Expand the main MA study area to 15 states
    - Existing 9 states: IL, IN, IA, MI, MO, KY, OH, TN, WV
    - New, additional 6 states: AL, AK, MS, GA, NC, SC
- Principles of configuration
  - Start with 48 states
    - Exclude Alaska and Hawaii
    - Include District of Columbia in Maryland
  - Refer to NTARs (National Transportation Analysis Regions) and BEA (Bureau of Economic Analysis) Economic Areas
  - Units of analysis are consistent with state boundaries

83 EQAZ Map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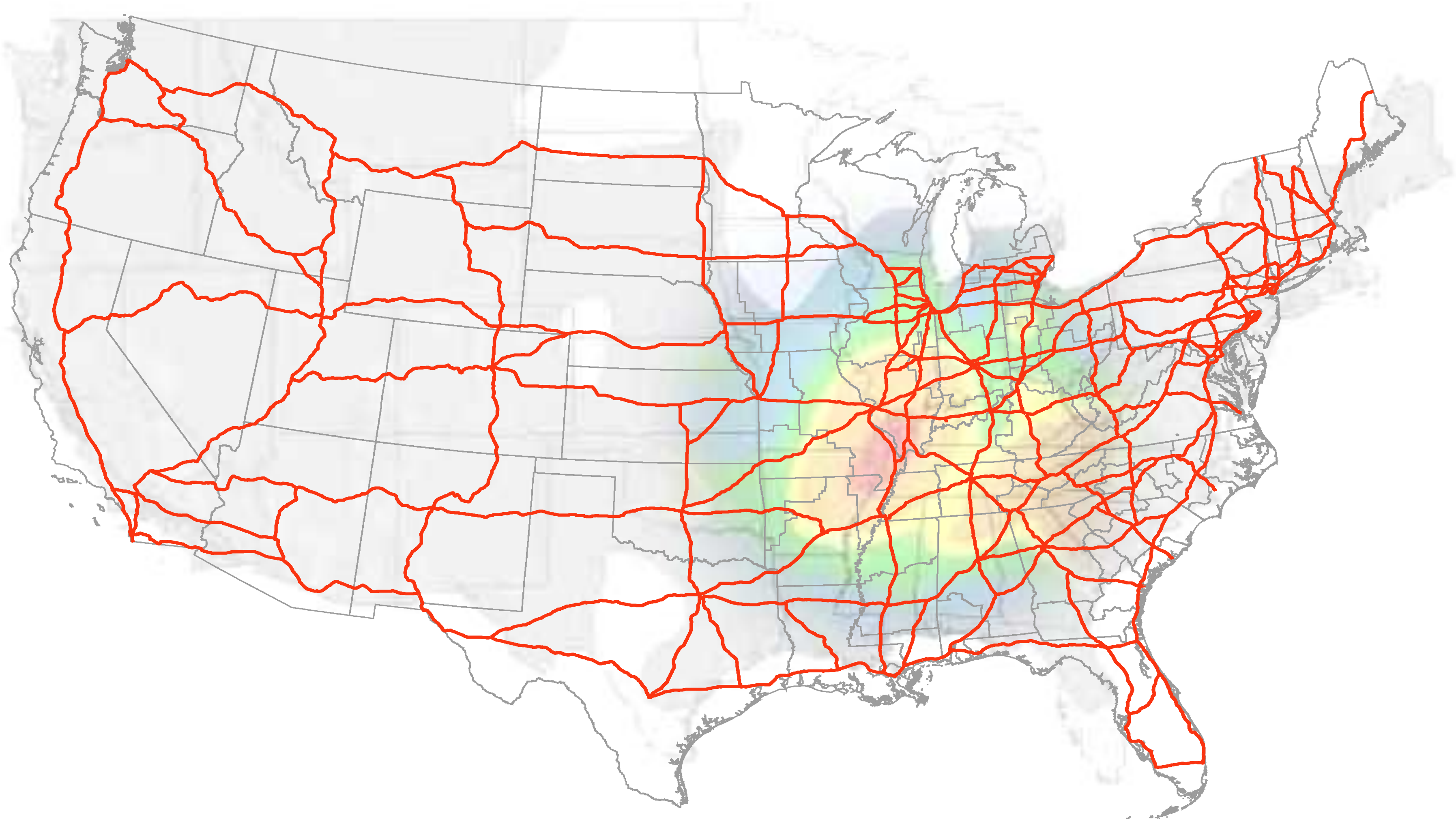
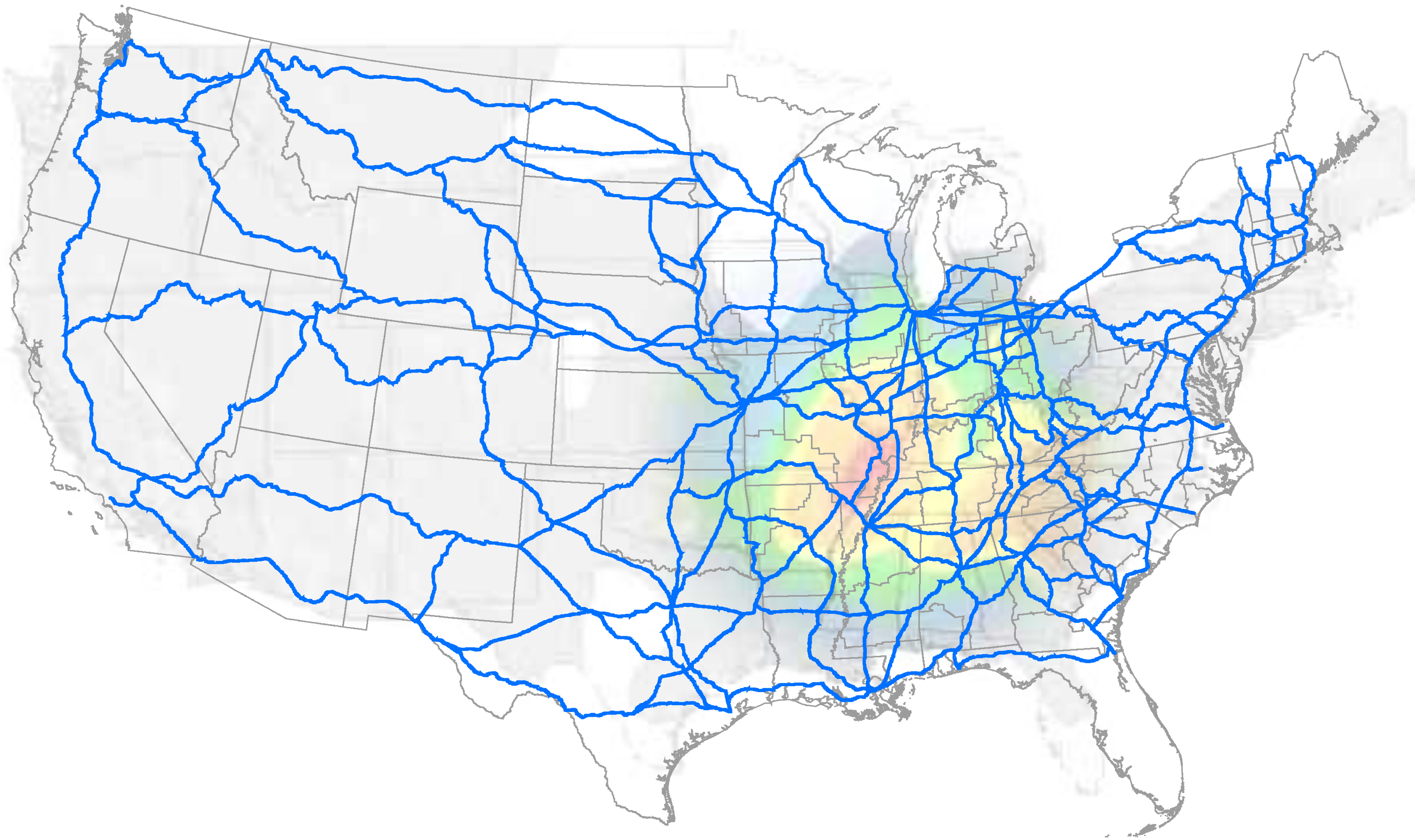
Highway Network



Railway Network



Temporal Configuration

- Disaggregate annual economic data into quarterly
  - Calculated the temporal shares by quarter (1972~2003)
    - Quarterly State Personal Income for agriculture, forestry, and fishery (BEA)
    - Monthly Employment for mining, construction, manufacturing, services and etc. (BLS)
- Testing of continuous time econometric-input-output model complete

Temporal Configuration

SUMMARY OF MW-REIM MODEL ESTIMATION

- **Model components:**
  - The Midwest 13-sector model comprises of 5 components:
  - Final Demand, Employment, Income, Output, Inter-industry relationships
- **Estimation:**
  - Each block is estimated separately first, and later they are put together.
  - There are 72 endogenous variables and 47 exogenous variables in the model.
  - All the equations are defined at the 1st order, while eight of them are defined at the 2nd order through defining a new variable.
  - 7 of the remaining equations are balance equations.

Project Methodology - 2

Model Formulation

- Integrated the Standard Interregional Flow Model with a Transportation Network Model
- A Development of a Network-Based Commodity Model based on Wilson(1970), and Leontief and Strout (1963)
- The proposed model minimizes the total shipment cost subject to several constraints

Integrated Commodity Flow Model

$$\min_{\bar{h},\bar{x}} \quad Z(\bar{h},\bar{x}) = \sum_{aw}\int_0^{f_a^w} d_a^w(\omega)d\omega + \sum_{mjw}\left(\frac{x_{jj}^{mw}}{g^m}\right)d_{jj}^w + \sum_m \frac{1}{\alpha^m g^m}\sum_{ijw} x_{ij}^{mw}\ln\left(\frac{x_{ij}^{mw}}{x_{ij}^m}\right)$$

$$+\sum_m \frac{1}{\beta^m g^m}\sum_{ij} x_{ij}^m \ln\left(\frac{x_{ij}^m}{\bar{X}_i^m}\right)$$

$$s.t. \quad \sum_i x_{ij}^m = \sum_n a^{mn}\sum_k x_{jk}^n + y_j^m \quad \textit{for all } m, j$$ Material balance

$$\sum_w x_{ij}^{mw} = x_{ij}^m \quad \textit{for all } m, i, j$$ Conservation of OD flow

$$\sum_r h_{ijr}^{mw} = \frac{x_{ij}^{mw}}{g^m} \quad \textit{for all } m, i, j, w$$ Conservation of route flow

$$h_{ijr}^{mw} \geq 0 \quad \textit{for all } m, r, i, j, w$$ Non-negativity

Integrated Commodity Flow Model

Exogenous variables

a^{mn} = technical input-output coefficient representing the inputs from sector m required to make one unit of output of sector n

α^{m} = cost sensitivity parameter for sector m

β^{m} = cost sensitivity parameter for sector m

g^{m} = factor for converting sector m from dollars to tons (\$/ton)

$\bar{X}_i^m$ = total estimated output of sector m in region i (\$)

y_j^m = final demand (consumption, investment and government expenditures) for sector m in region j (\$)

Integrated Commodity Flow Model

Endogenous variables

$d_a^w(f_a^w)$ = distance function of total flow on link a by mode w (miles)

d_{jj}^w = intraregional distance for region j by mode w (miles)

f_a^w = total flow on link a by mode w (tons)

$$= \sum_m \sum_{ijr} h_{ijr}^{mw} \delta_{ijr}^a$$

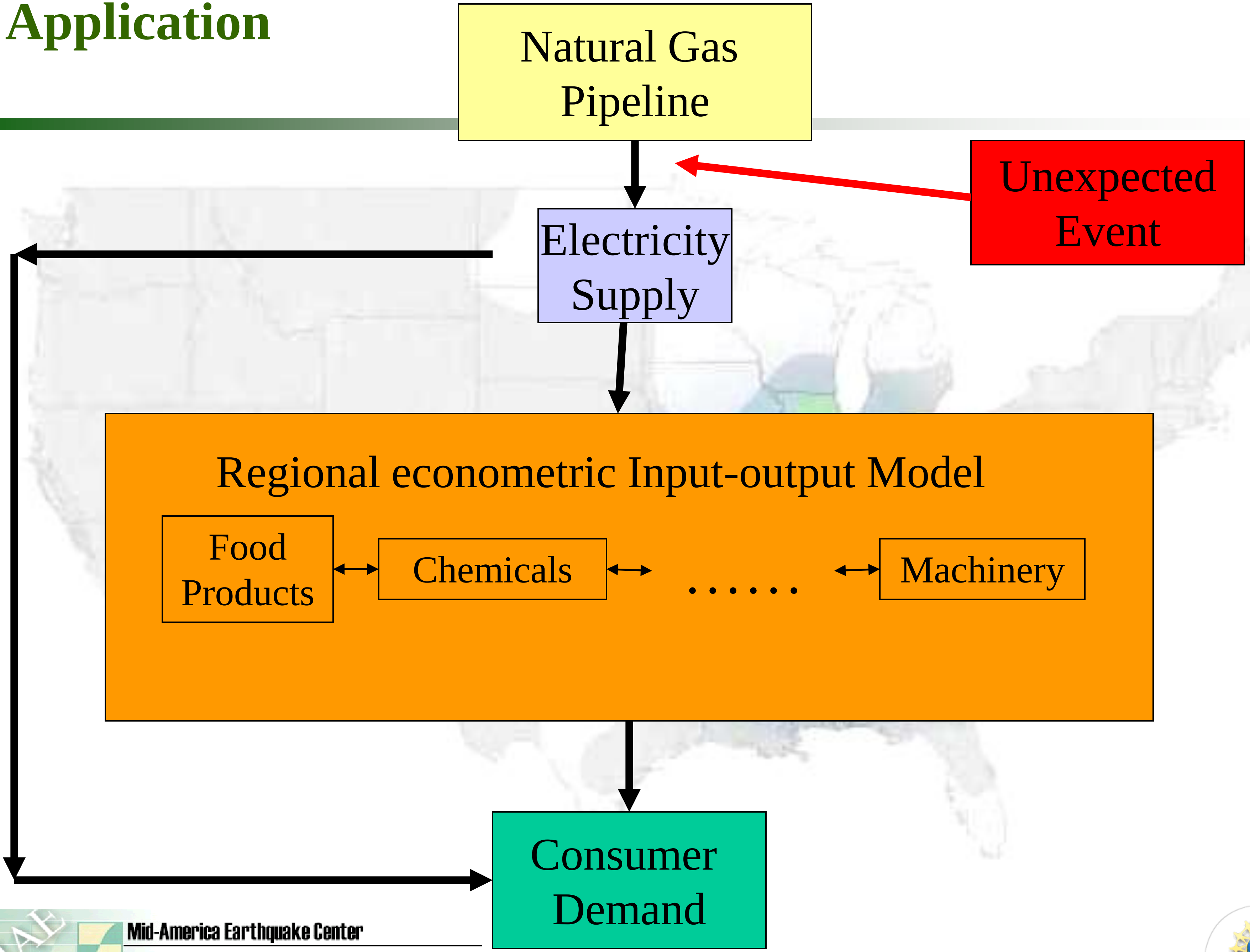
δ_{ijr}^a = 1 if link a belongs to route r from region i to region j, and 0 otherwise

h_{ijr}^{mw} = flow of output of sector m from region i to region j on route r by mode w (tons)

x_{ij}^m = flow of output of sector m from region i to region j ($)

x_{ij}^{mw} = flow of output of sector m from region i to region j by mode w ($)

Application



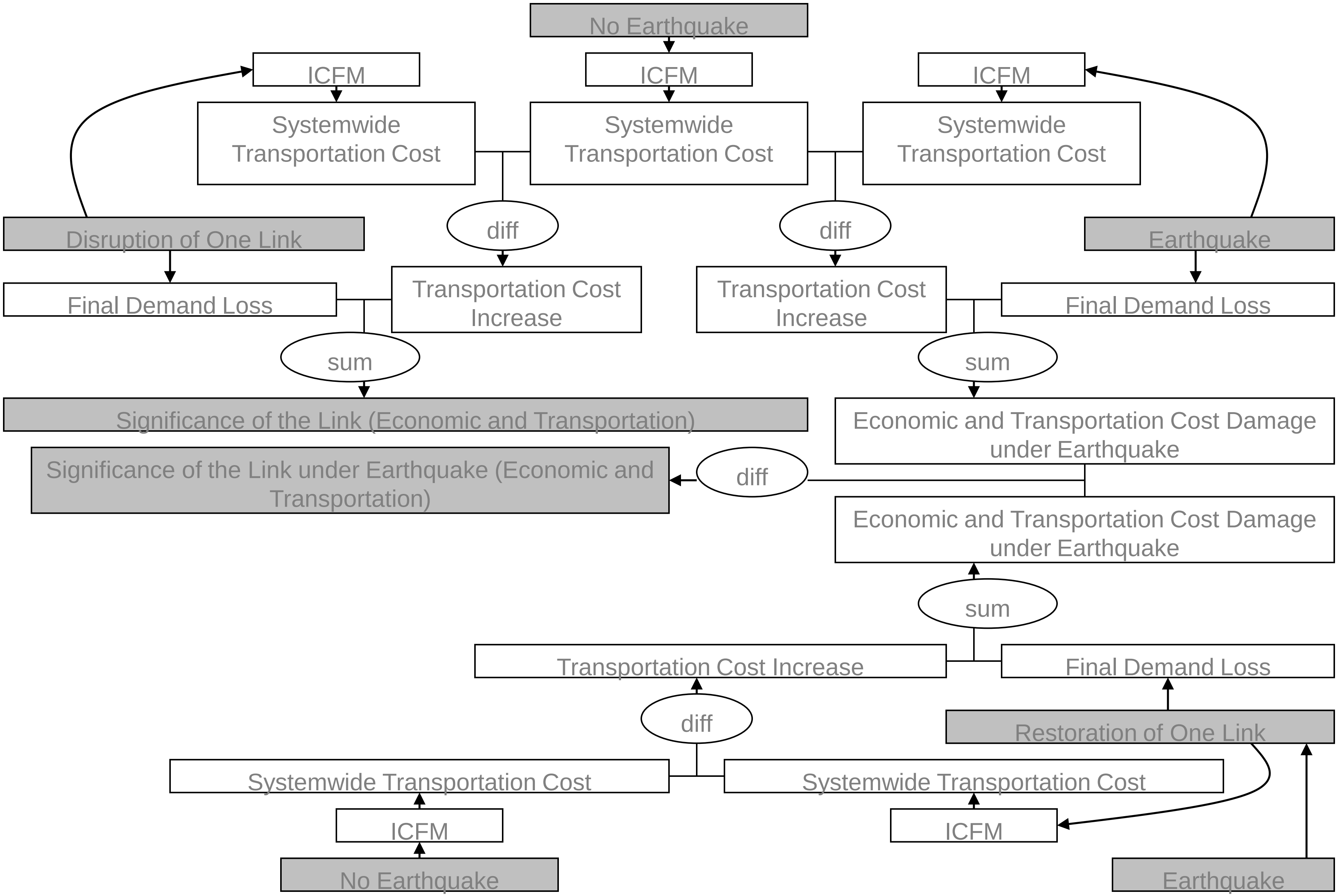
Comparison with US EPA Modeling System

	SE-11	HAZUS
Scope	Transportation network (bridges)	Comprehensive
Direct economic loss (model)	Fragility function	Fragility function
Direct economic loss (outcome)	Disruption ratio	Damage cost
Indirect economic loss (model)	I-O and ICFM	I-O
Indirect economic loss (outcome)	Final demand and system transport cost	Output, income and employment
I-O table	Multiregional	Regional or national
Initial shock	Total output or final demand	Total output (proportional change in forward- and backward-linkage coefficients
Sectoral resiliency	O	X
Sectoral loss	O	O
Zonal loss	Multiple zones	Single zone
Time span	One year	Multiple year

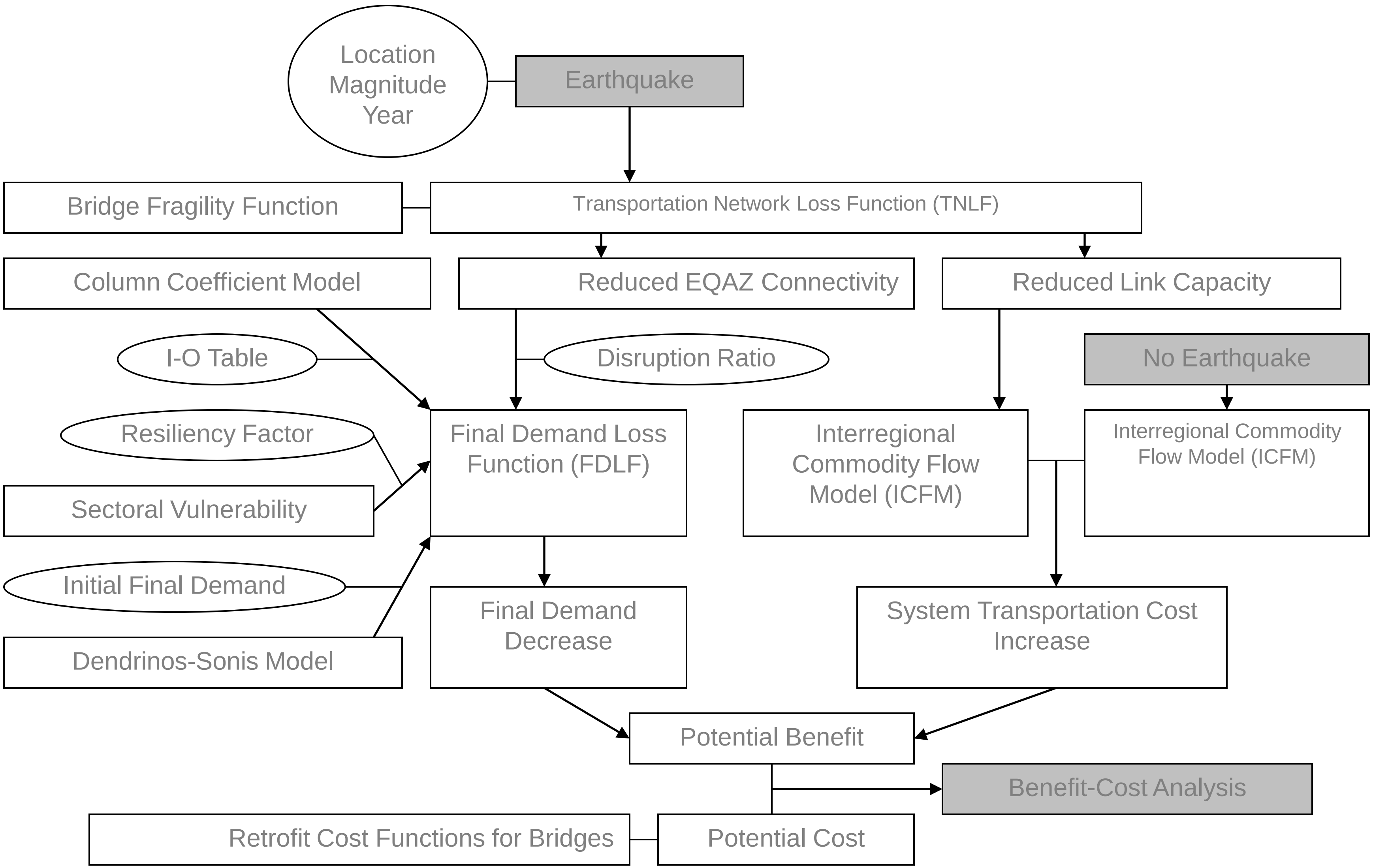
Critical Link Analysis

- Assume demand unchanged
- Critical link identification in general case
  - Assume the complete disruption of individual links and calculate the cost of re-routing
  - Compare the cost differential with the one with no disruption
- Critical link identification under an earthquake
  - Run the model assuming an earthquake
  - Calculate cost saving if a disrupted link works with full capacity
  - Obtain a ratio of cost saving to disruption ratio

Critical Link Analysis



Scenario Analysis



Final Demand Loss Analysis

- Disruption of transportation network ➔ final demand change
- Need to estimate **Disruption ratio**
- **Resiliency factors** – ability of sector to recover from disruption
- Compare with initial final demand before the earthquake

Final Demand Loss Analysis

$$\Delta f = (I - A)\{[D \otimes (1_{13} - R)] \circ [(I - A)^{-1} f]\} \quad (8)$$

where

$A = 13$ sector by sector direct input coefficient by zone (468×468)

$D =$ network disruption ratio by zone (36×1)

$1_{13} - R =$ one minus sectoral resiliency factor vector (13×1)

$f =$ final demand by sector by zone before the earthquake (468×1)

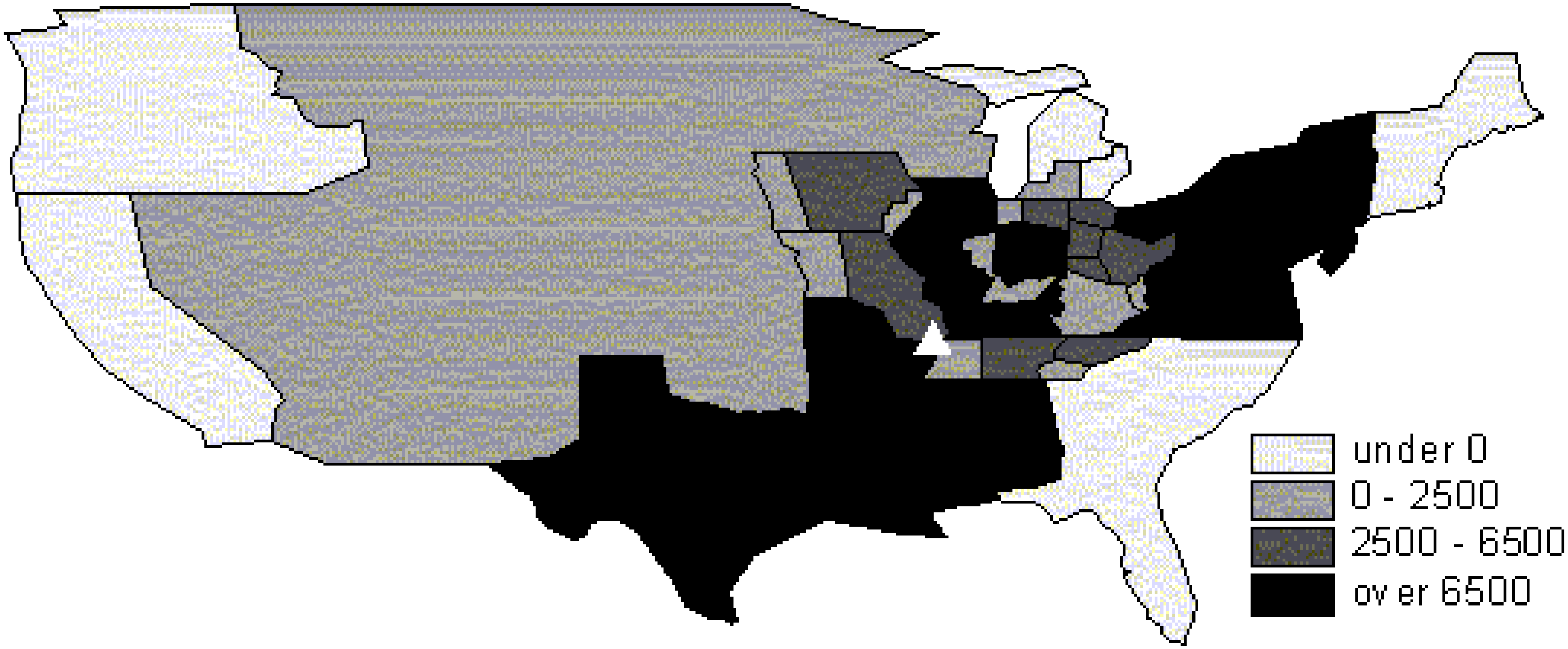
$$\otimes \text{ is the tensor defined as } B \otimes G = \begin{pmatrix} b_{11}G & \cdots & b_{1j}G & \cdots & b_{1n}G \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{i1}G & \cdots & b_{ij}G & \cdots & b_{in}G \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{m1}G & \cdots & b_{mi}G & \cdots & b_{mn}G \end{pmatrix}_{mp \times nq}$$

$$\text{where B} = \left(b_{ij}\right)_{m \times n} \text{ and G} = \left(g_{ij}\right)_{p \times q}$$

$$\circ \text{ is defined as } B \circ G = \begin{pmatrix} b_{11}g_{11} & \cdots & b_{1j}g_{1j} & \cdots & b_{1n}g_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{i1}g_{i1} & \cdots & b_{ij}g_{ij} & \cdots & b_{in}g_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{m1}g_{m1} & \cdots & b_{mi}g_{mi} & \cdots & b_{mn}g_{mn} \end{pmatrix}$$

$$\text{where B} = \left(b_{ij}\right)_{m \times n} \text{ and G} = \left(g_{ij}\right)_{m \times n}$$

Final Demand Loss Analysis



Resiliency Factors

$$r_k = r_k^{IZ}(1 - r_k^{HW}) + r_k^{AD} + \varepsilon_k \qquad (12)$$

where

$r_k^{IZ} = \dfrac{\sum_{m=1}^{36} f_{mm}^k}{f^k}$ = relative ratio of intrazonal flow of sector k

f_{mm}^k = commodity flow of sector k from m to m (intrazonal flow)

f^k = total commidity flow of sector k

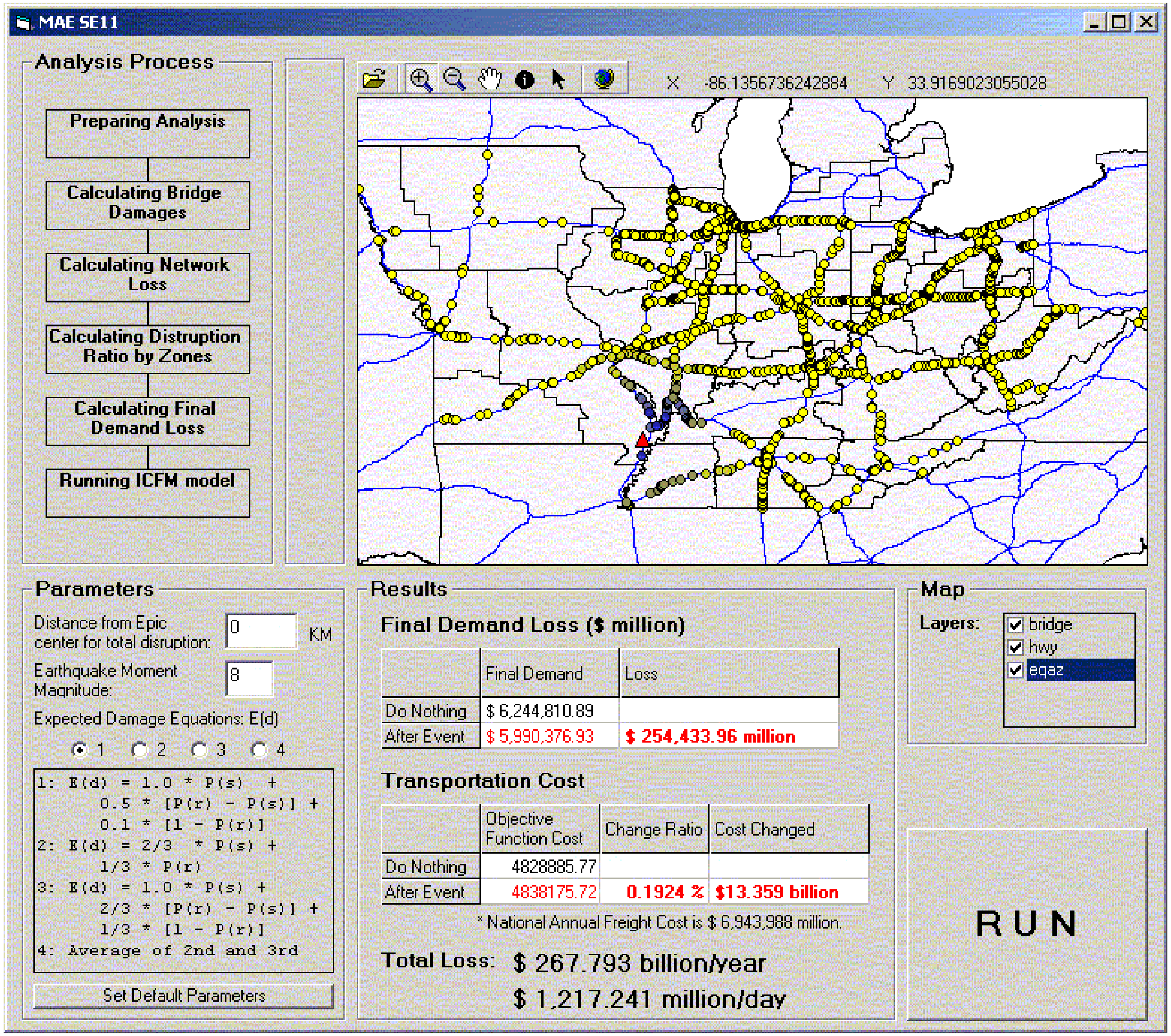
r_k^{HW} = modal share of highway in sector k

r_k^{AD} = standardized inversed average shipment distance of sector k on highway

ε_k = a universal random variable or error term that satisfy $N(0, \sigma^2)$

Sector 1	.4246
Sector 2	.3682
Sector 3	1.0000
Sector 4	.0944
Sector 5	.2446
Sector 6	.0766
Sector 7	.0168
Sector 8	.0273
Sector 9	.0152
Sector 10	.1090
Sector 11	.3907
Sector 12	.1275
Sector 13	.1824
Total	.2397

Model Software



Issues

Issues to be addressed

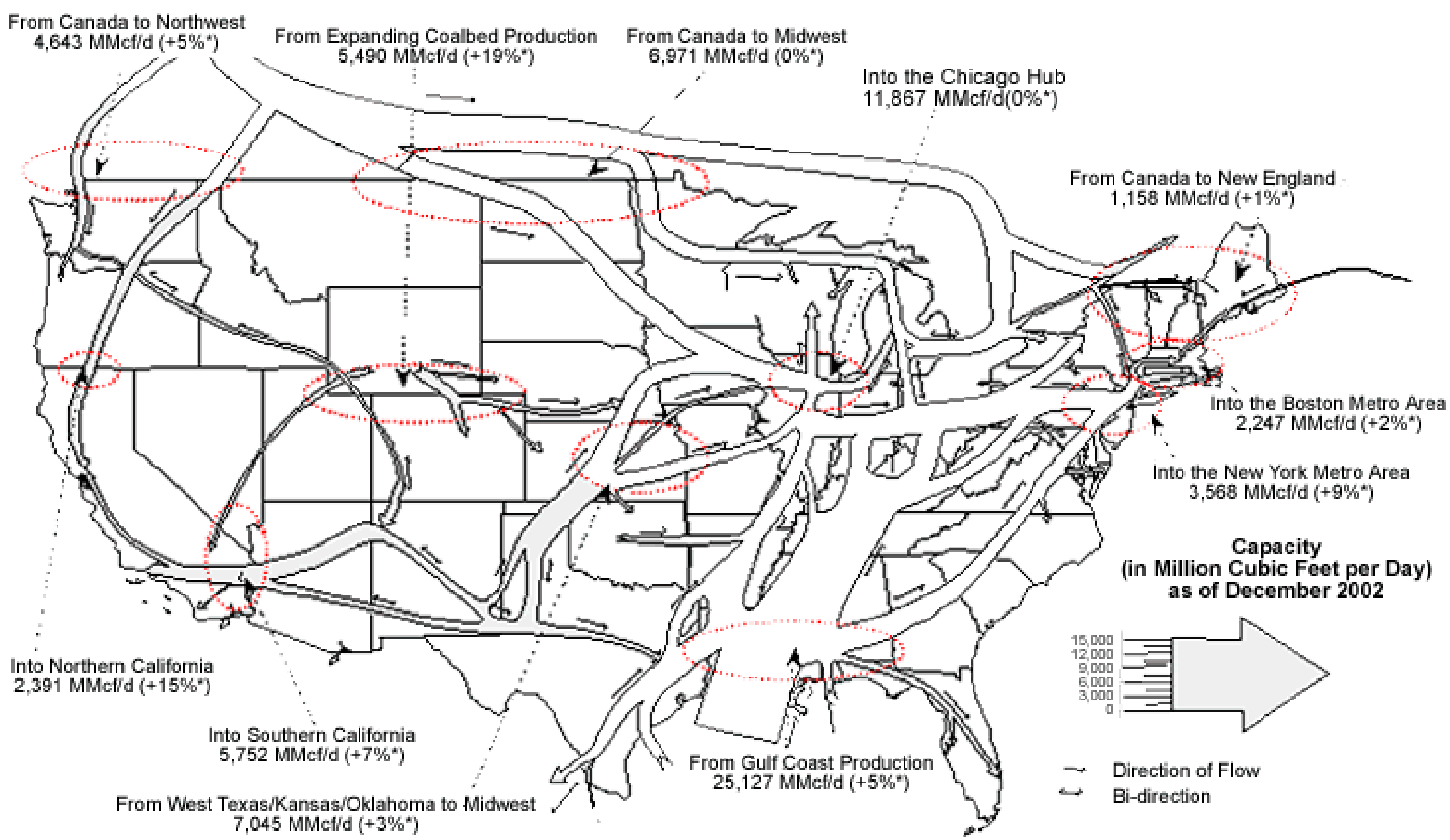
- How can a disruption in natural gas supply be handled
  - Bring other non-gas units on line
  - Import electricity from other regions
  - Reduce supplies to major customers

Problems

- De-regulation squeezed capacity margins
- Interregional transmission capacity limited (public goods problem)
- Earthquake likely to disrupt many pipelines and reduce supplies over wide area

Issues

Major Natural Gas Transportation Routes at Selected Key Locations, 2002



*Percent change since 2000.
Source: Energy Information Administration, GasTran Gas Transportation Information System, Natural Gas Pipeline State Border Capacity Database.

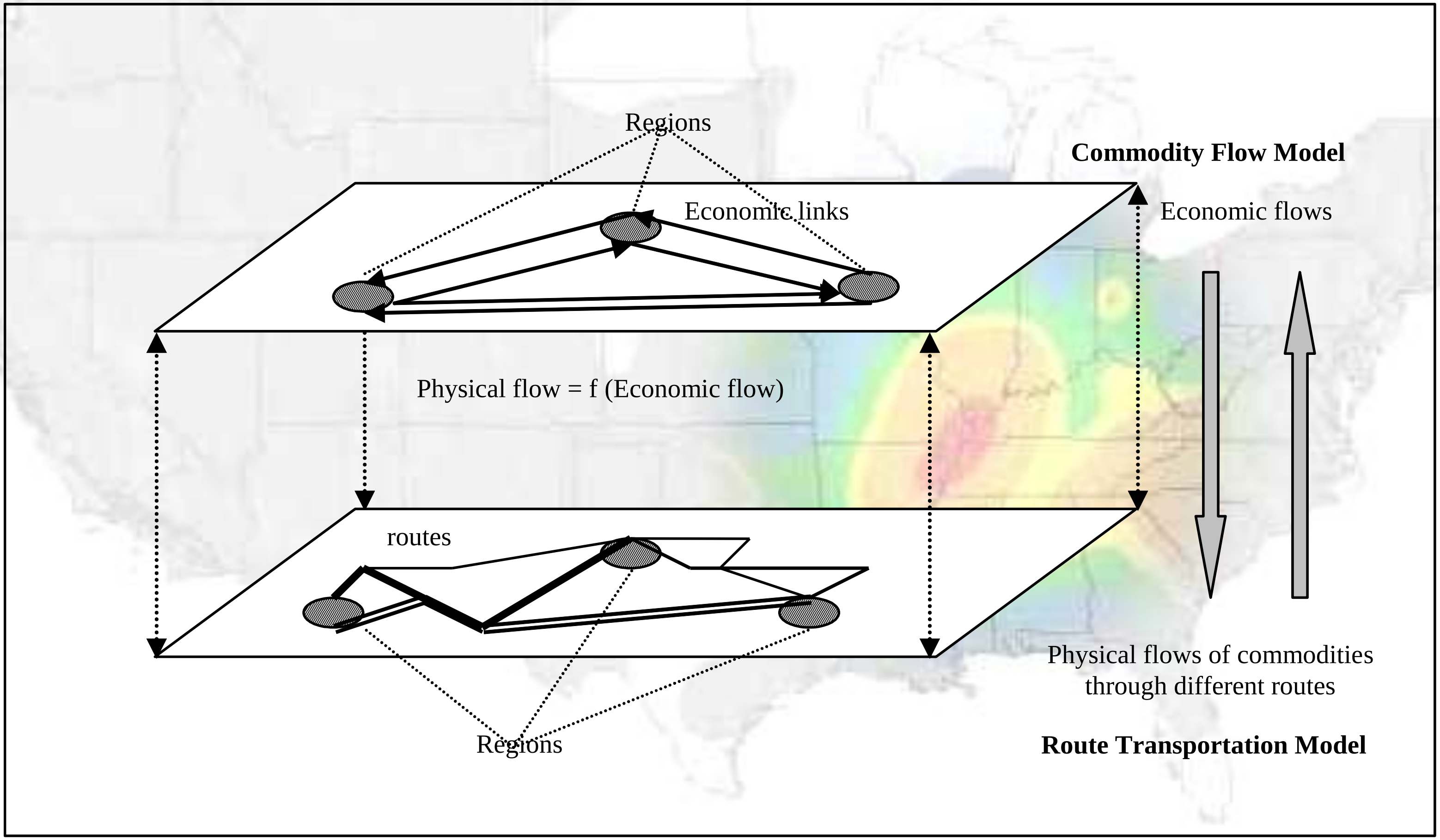
Gas dependency Varies by State

Percentage Distribution of Natural Gas Deliveries, 2001
Illinois, Indiana, and Missouri

	Residential	Commercial	Industrial	Vehicle Fuel	Electric Power
Illinois	45.52%	20.16%	29.55%	0.03%	4.74%
Indiana	29.80%	15.87%	50.71%	0.06%	3.55%
Missouri	41.22%	23.03%	24.07%	0.04%	11.64%

Integrating Models

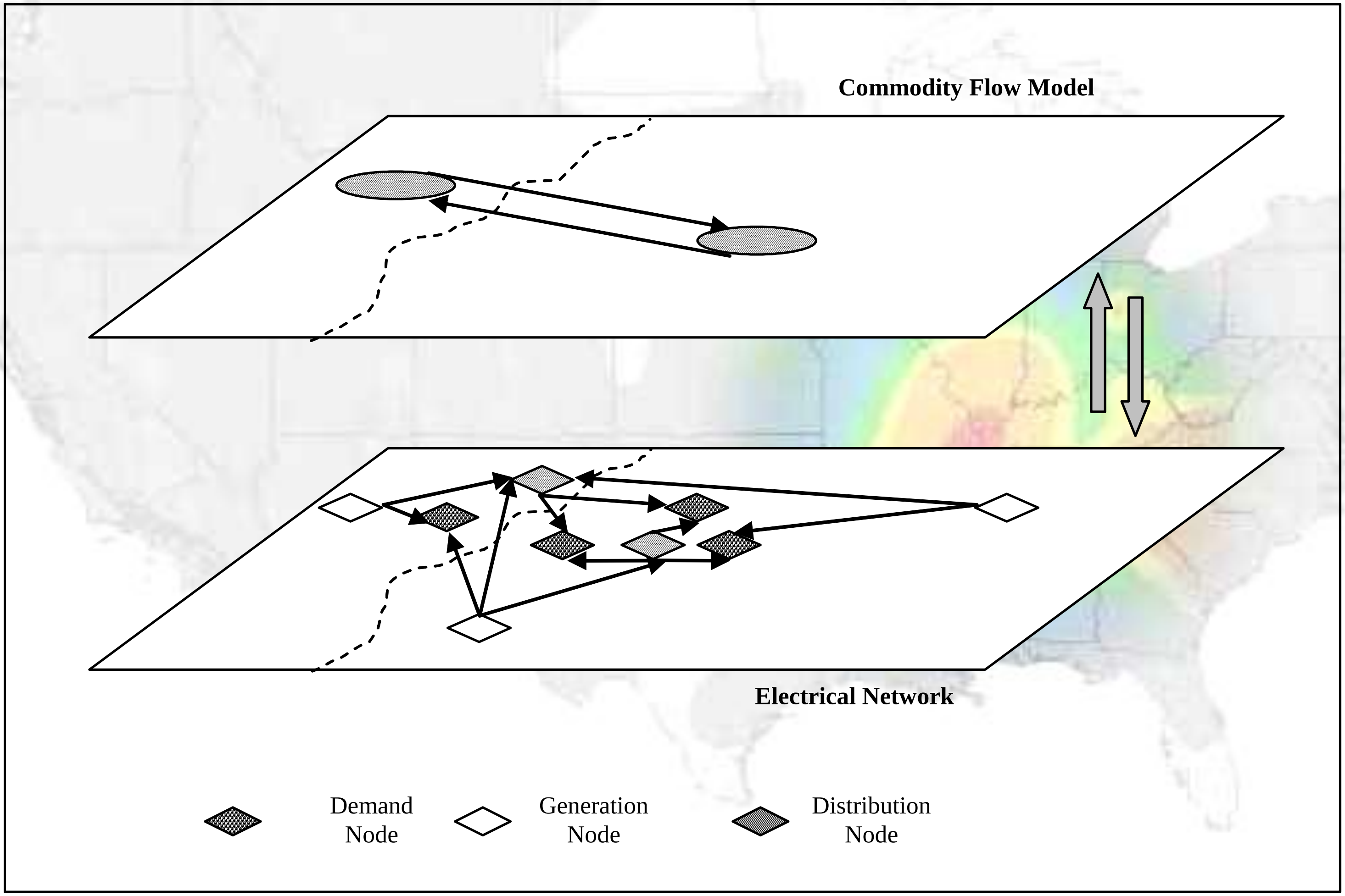
A representation of a combined economic model and transportation model



Integrating Models

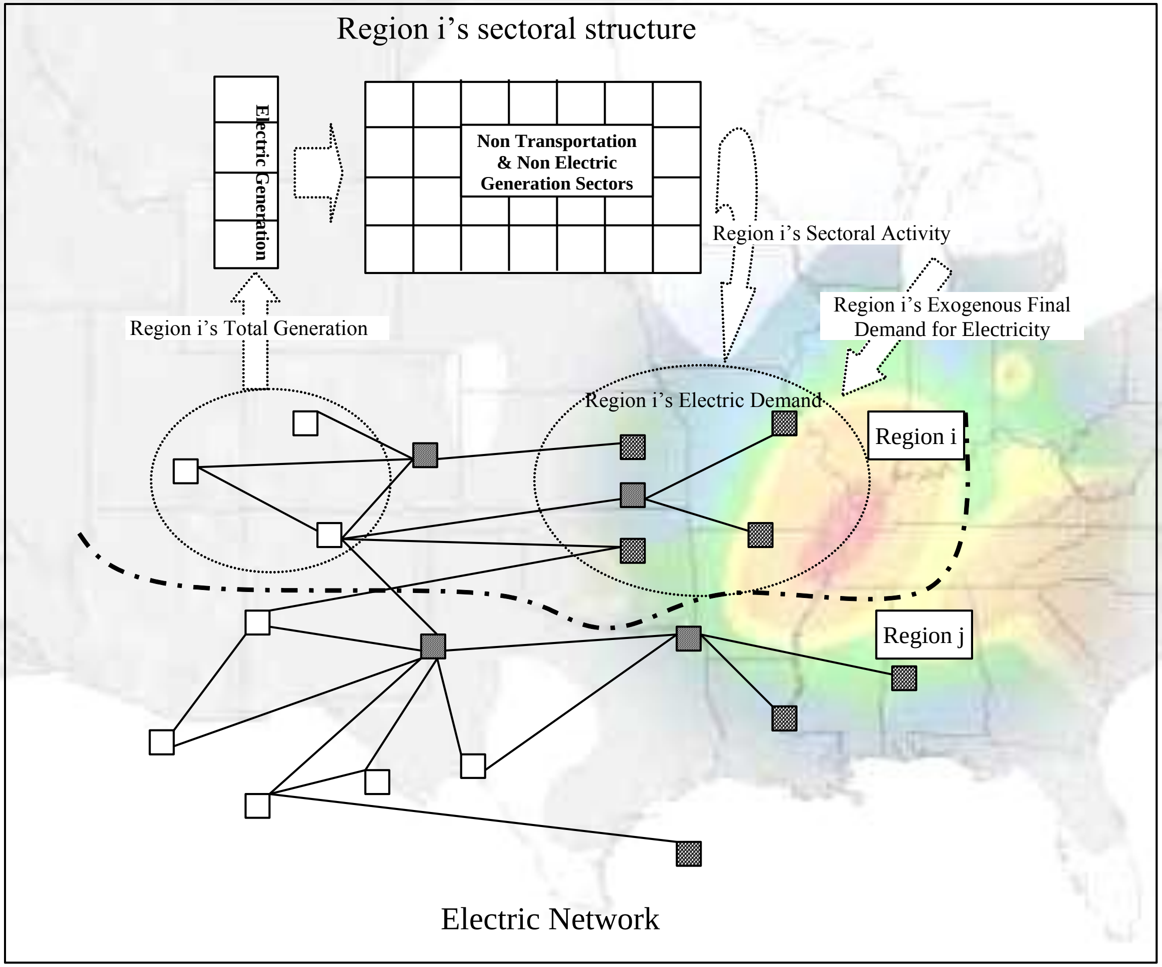
Networks covering the same geographical area

with different levels of disaggregation

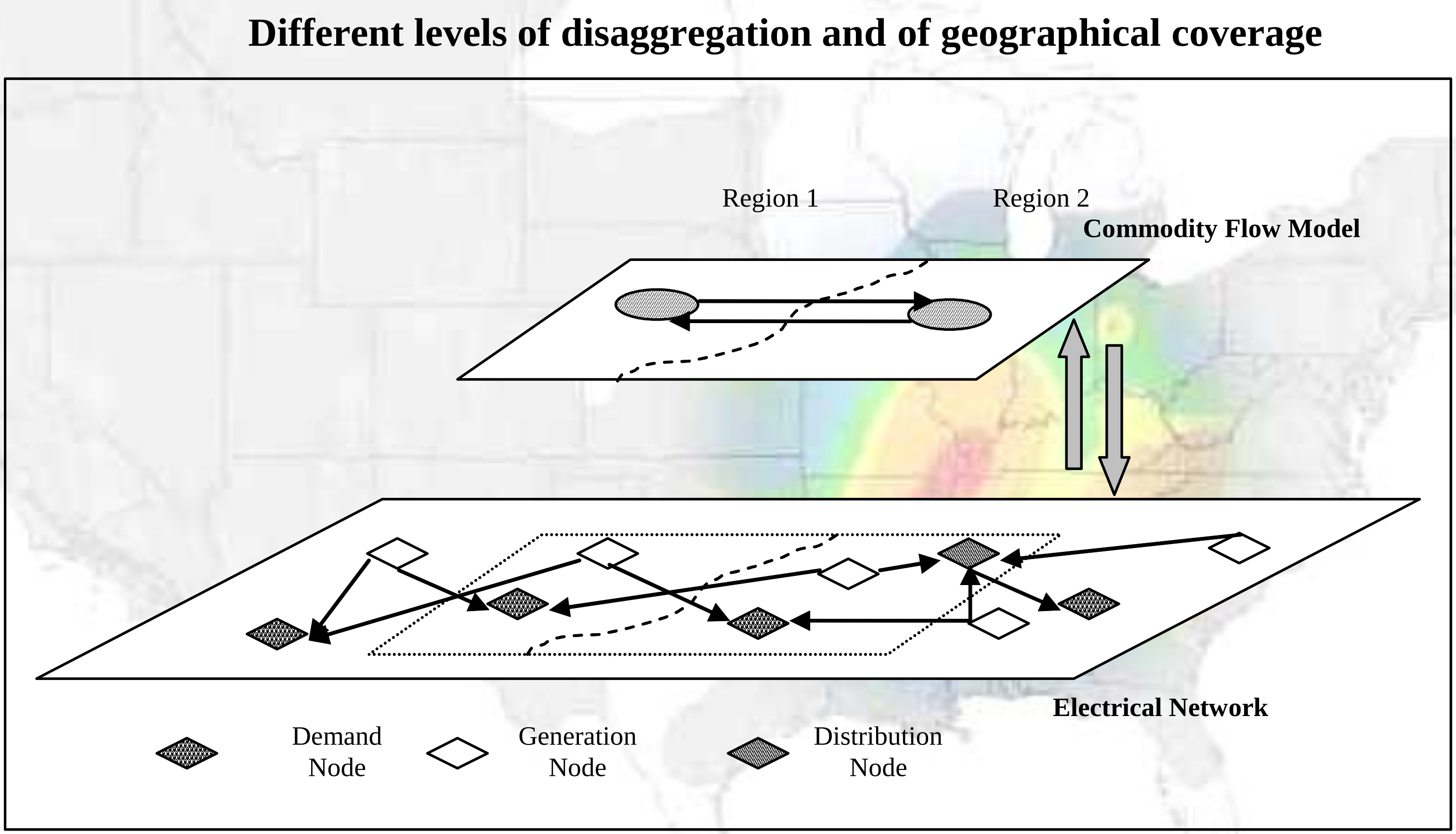


Integrating Models

A spatially disaggregated network and its connections to a commodity flow model

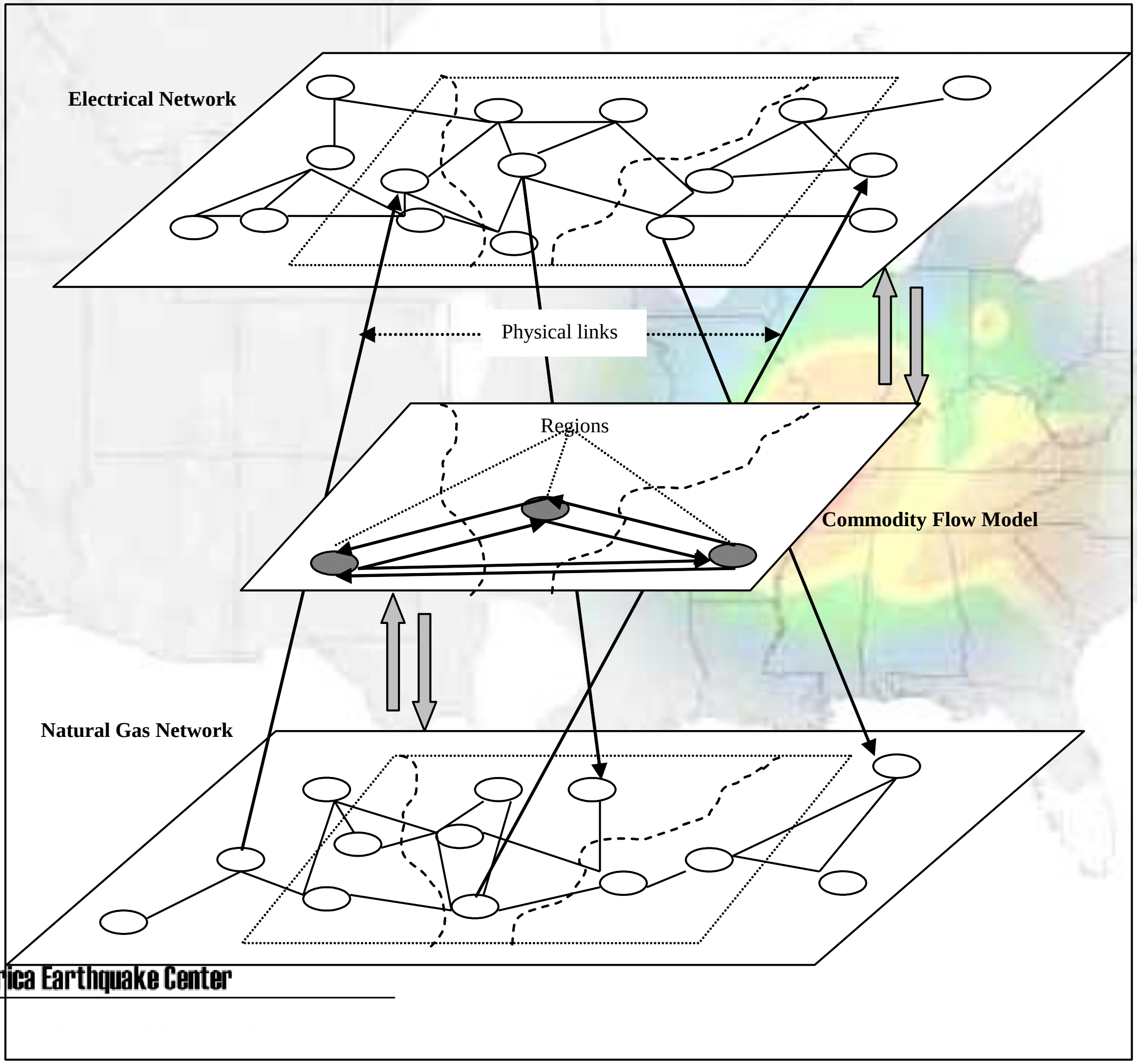


Integrating Models



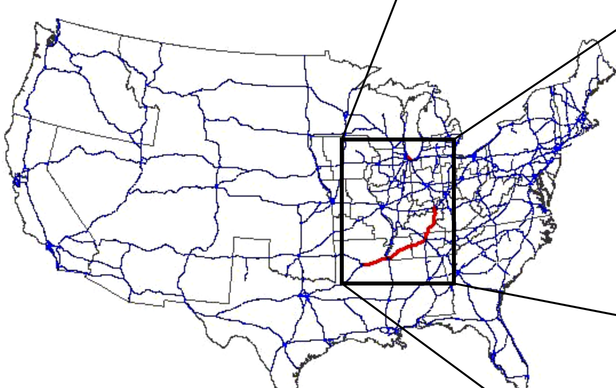
Integrating Models

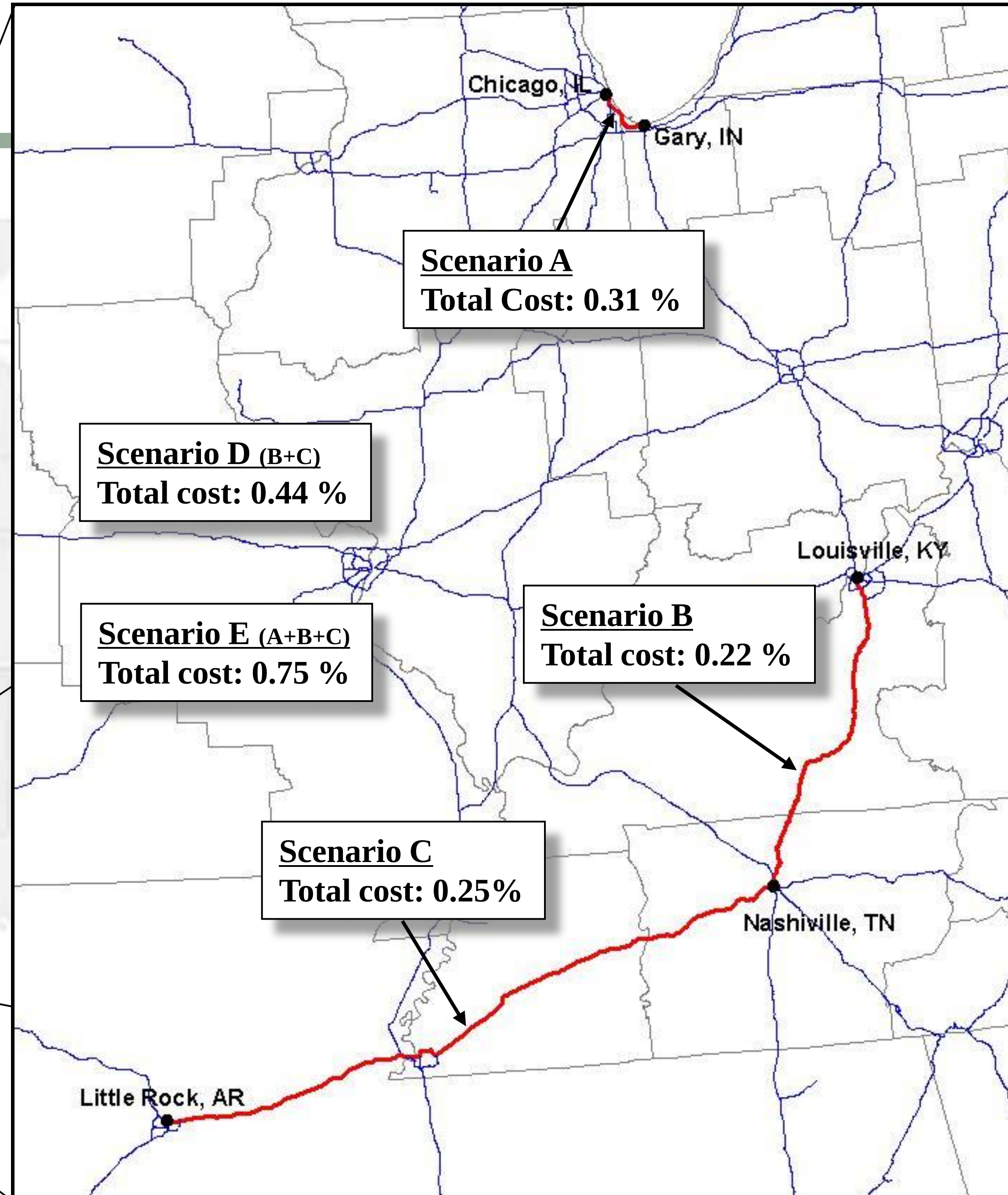
An economic network, an electric power network, and a natural gas network for different disaggregation levels and geographic coverings



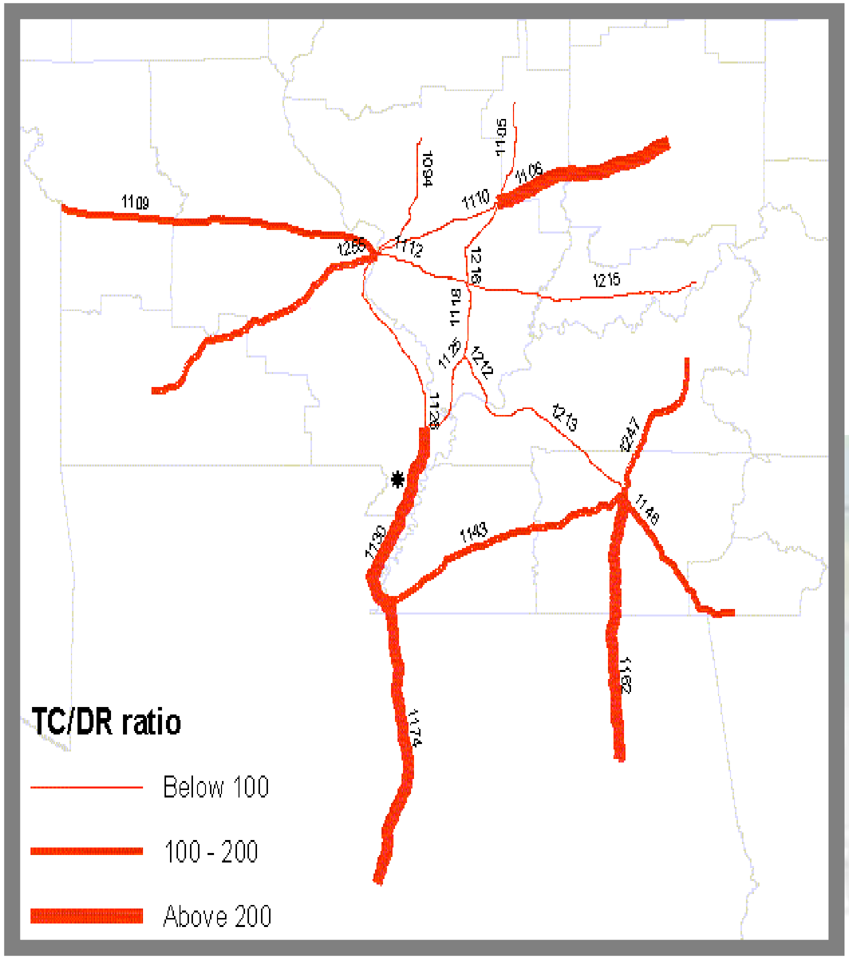
Work Completed

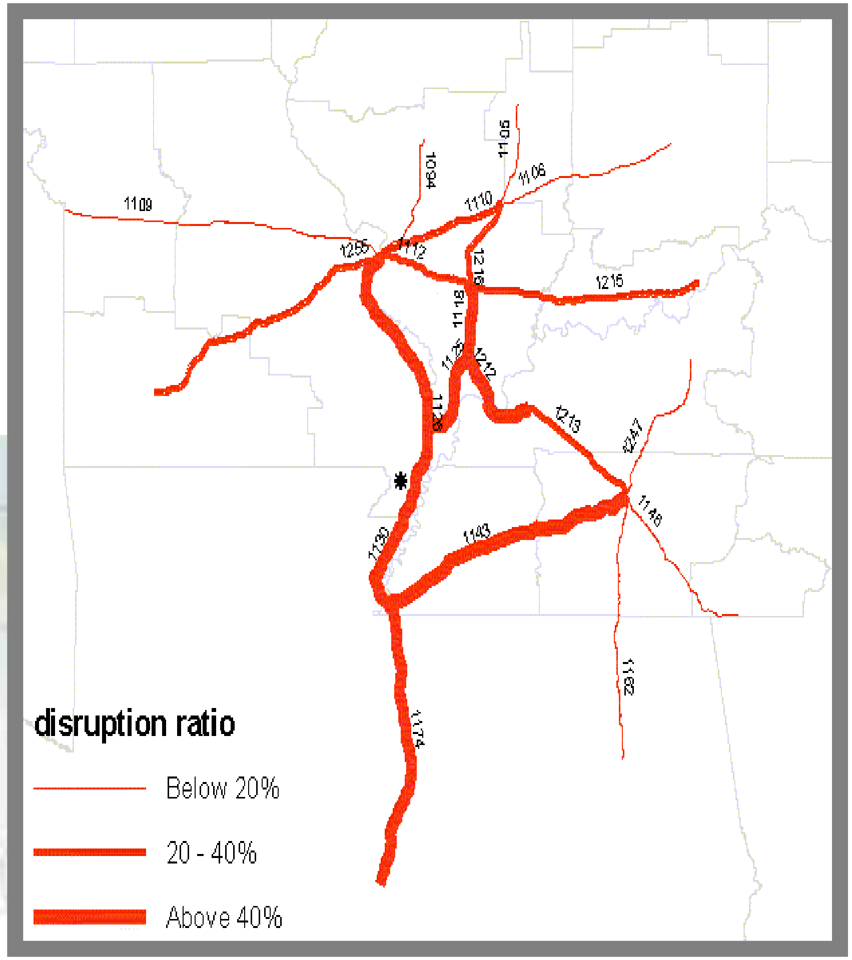
Percentage changes of objective function value (total transportation cost)



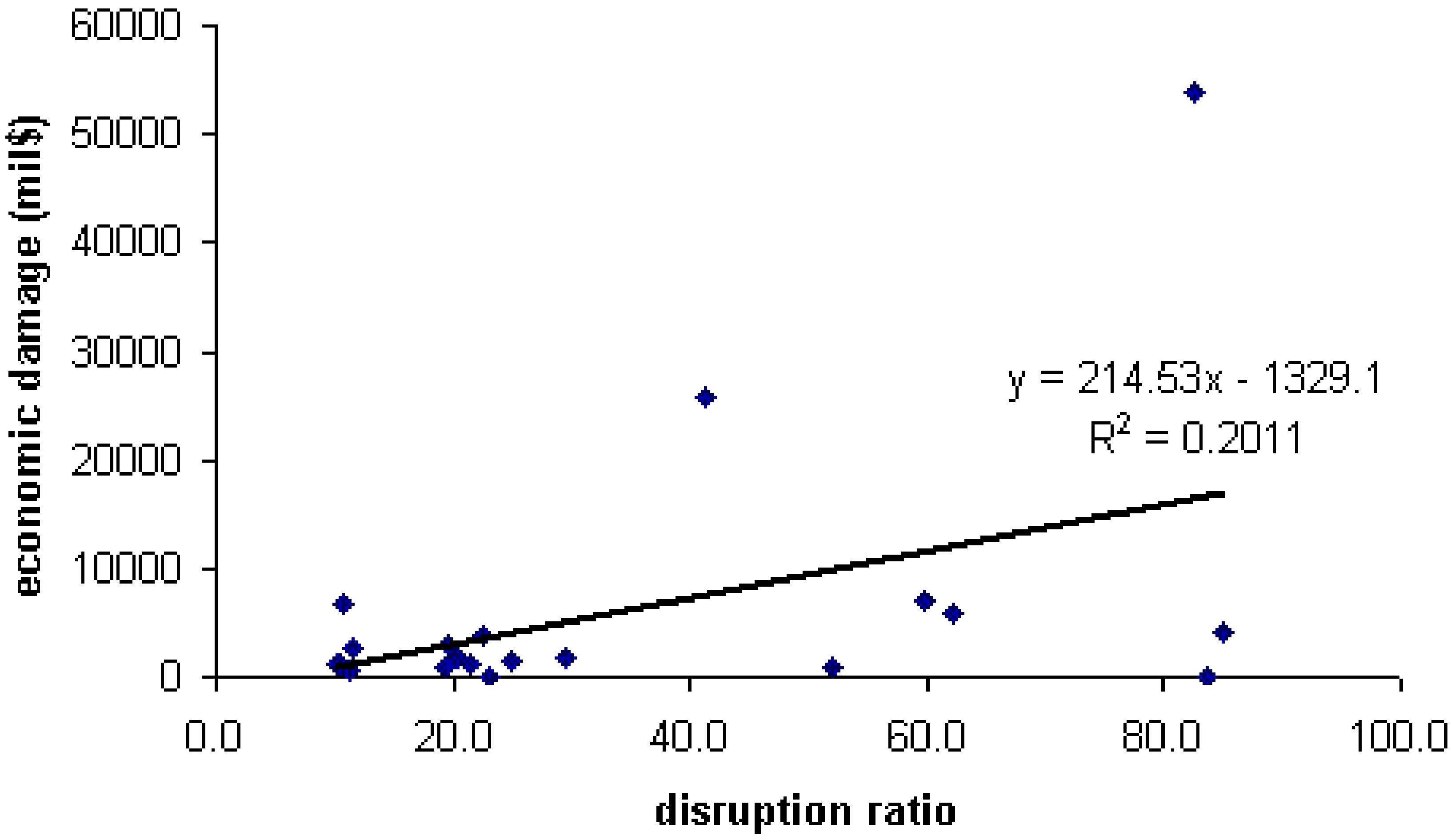


Economics vs. Engineering





Economics vs. Engineering



Treatment of Uncertainty

- Uncertainties in this project include uncertainties in obtaining detailed transportation flow data, both spatially and temporally
    - New proposal will focus on errors in estimation
    - Access to micro data
- In the absence of such data, spatial econometric methods will be used to generate spatial and temporal data needed as input to spatial and temporal network models.
- System has the potential to incorporate retrofit cost data should this become available
- This will be necessary to conduct cost-benefit analysis of optimal retrofit strategies

Future Work

- Integration of continuous time version
- Link with power distribution networks
- Simulation of disruption
- Incorporating feedbacks from transportation network to the economic production system
- Testing with stakeholders