Resiliency Planning in Transportation

Practical Software Tools and Long-Term Visions

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Overview of Topic

- Definitions of Resiliency
  - General Definition
  - Transportation Context
- Software tools review
  - CARVER^2
  - TRAGIS
- Overview of NETSCORE & Netplan
  - Research Description
  - Sample Results
  - Ongoing issues & considerations

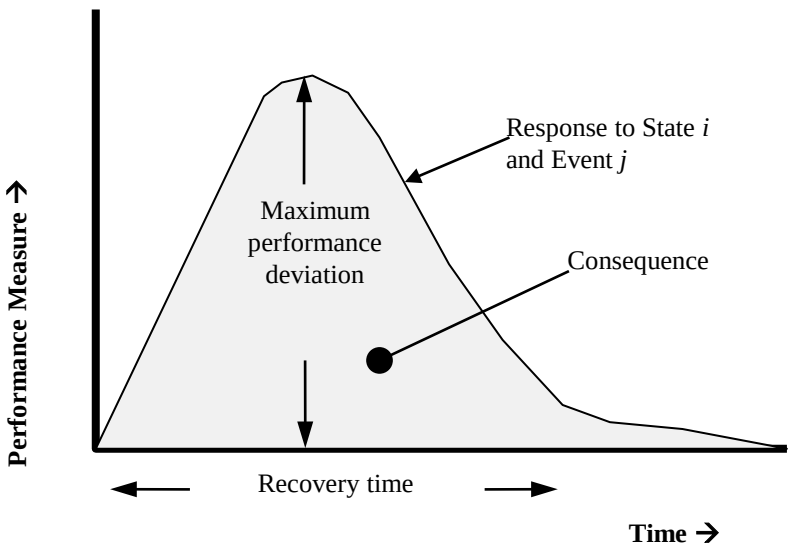
What is Resiliency?

- Communications: “The ability to provide and maintain an acceptable level of service in the face of faults and challenges to normal operation”[1]
- Process Control: “The ability of a system to return to its original (or desired) state after being disturbed”[2]
- Aerospace: “The ability to change when a force is enacted, and the ability to perform adequately while the force is in effect.”[3]

1. J. P. Sterbenz, and D. Hutchison, “ResiliNets: Mutlilevel Resilient & Survivable Networking Initiative”, Aug. 2006, Retrieved September 2010, from University of Kansas Information and Telecommunication Technology Center.
2. M. Christopher, and C. Rutherford, “Creating Supply Chain Resilience Through Agile Six Sigma”, CriticalEYE , Vol. 5, 2004.
3. J. F. Castet, and J. Saleh, “Survivability and Resiliency of Spacecraft and Space-Based Networks: a Framework for Characterization and Analysis”, AIAA Space 2008 Conference & Exposition, San Diego, 2008

In a Transportation Context…

- Likelihood – The probability of an event occurring and the potential for it to disrupt the transportation network
- Severity – The impact of an event, in terms of lost network capability which has occurred on transportation network performance



"Resiliency in long-term planning of the national energy and transportation systems." Ibáñez, E.; Lavrenz, S.; Mejía, D.; Somani, A.; McCalley, J.. October 2010.

Evaluating Resiliency

- Planning for a resilient network will reduce the adverse impact of future disasters, technology changes, etc.
- Limited budgets generate fierce competition for current and future roads project needs.
- Resiliency is another tool which can be used to objectively evaluate a group of projects.
- A resilient transportation system "*can meet long-term economic, social and environmental goals under a wide range of unpredictable future conditions.*"[1]

1. "Evaluating Transportation Resilience". TDM Encyclopedia, Victoria Transport Policy Institute. Updated 26 January 2010. Retrieved 5 August 2011.

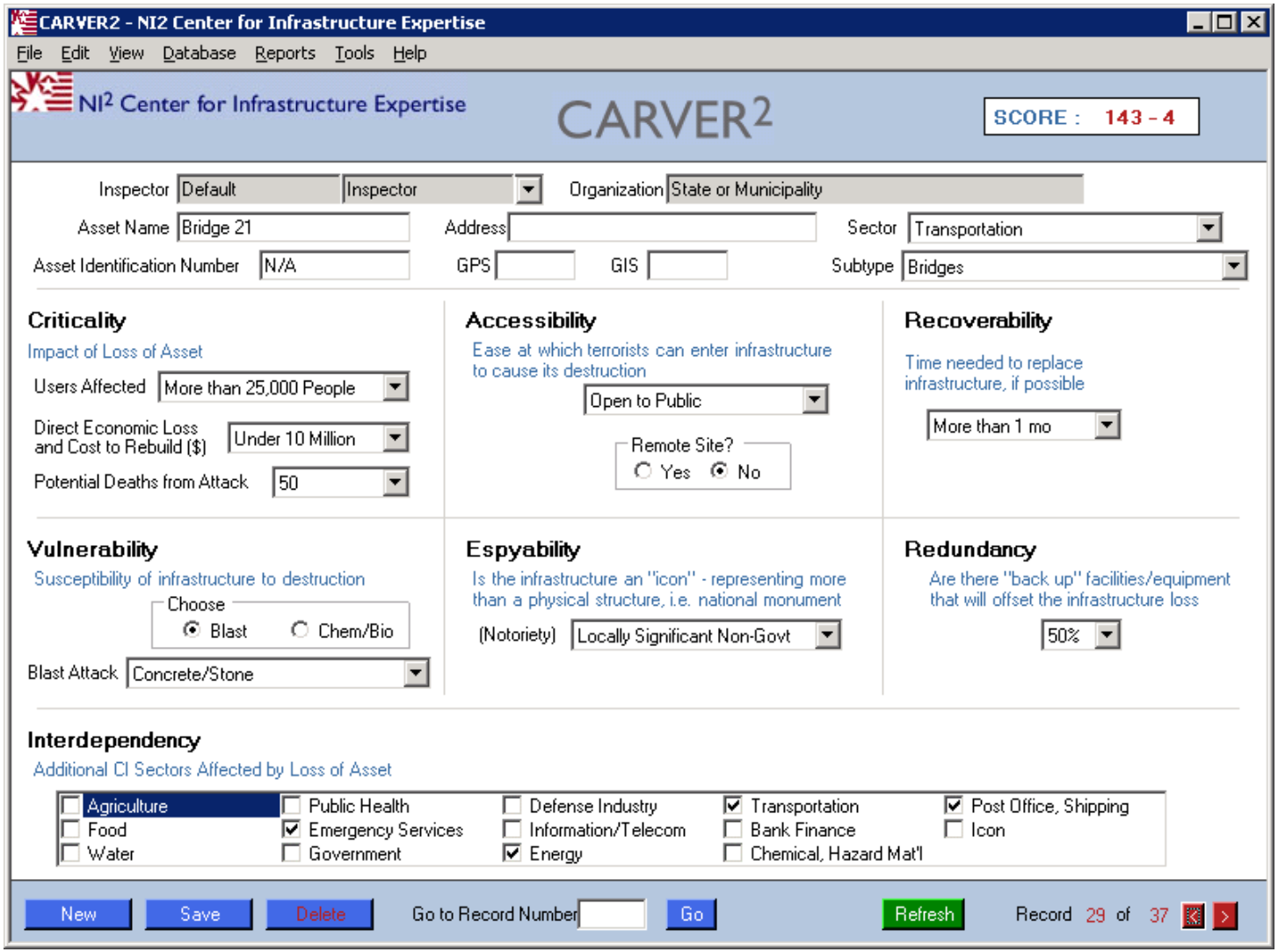
Resiliency Software Tools

- What sorts of tools are currently available to transportation professionals?
  - Not a whole lot
  - Tools which are purposed for resiliency and risk assessment, don't require a strong learning curve
- CARVER^2 & TRAGIS
  - Risk assessment and transportation routing
  - Easy to use, free, publically available (with restrictions)

CARVER^2 - Introduction

- **C**riticality **A**ccessibility **R**ecoverability **V**ulnerability **E**spyability **R**edundancy, version **2**
- Developed by NI^2 Center for Infrastructure Expertise
- Ranks infrastructure elements by threat of disruption and resulting effects
- Ranking done in terms of raw score – can be used for dissimilar infrastructure elements
- Can be used to assess likelihood in terms of infrastructure vulnerability.

CARVER² – User Interface



CARVER^2 – Scoring Areas

- Criticality
  - Affected Users
  - Direct Economic Loss & Rebuild Cost
  - Potential Deaths
- Accessibility
- Recoverability
  - Time frame to fully recover
  - Also can choose irreplaceable
- Vulnerability
  - Biological/Chemical Effects
  - Blast (Physical) Effects
  - Includes strengths and weaknesses
- Espyability (icon status)
- Redundancy
- Interdependency
  - 14 infrastructure areas to consider

CARVER^2 –Results Reporting

- $Total\ Score = \sum_{i=1}^{3} Criticality_i + Accessibility + Recoverability + Vulnerability + Espyability - Redundancy$
- Interdependencies not considered in scoring
- Numerous ways to group infrastructure elements and generate reports
  - Sector, sub-sector, interdependencies by sector, top 100 ranked assets, etc.

CARVER^2 – Pros & Cons

Advantages

- Uses standard database underpinnings
  - Batch element entry
  - Modification of scoring factors
  - Add/Remove other scoring elements
- Numerical scoring allows for comparison between dissimilar elements
- No technical training required

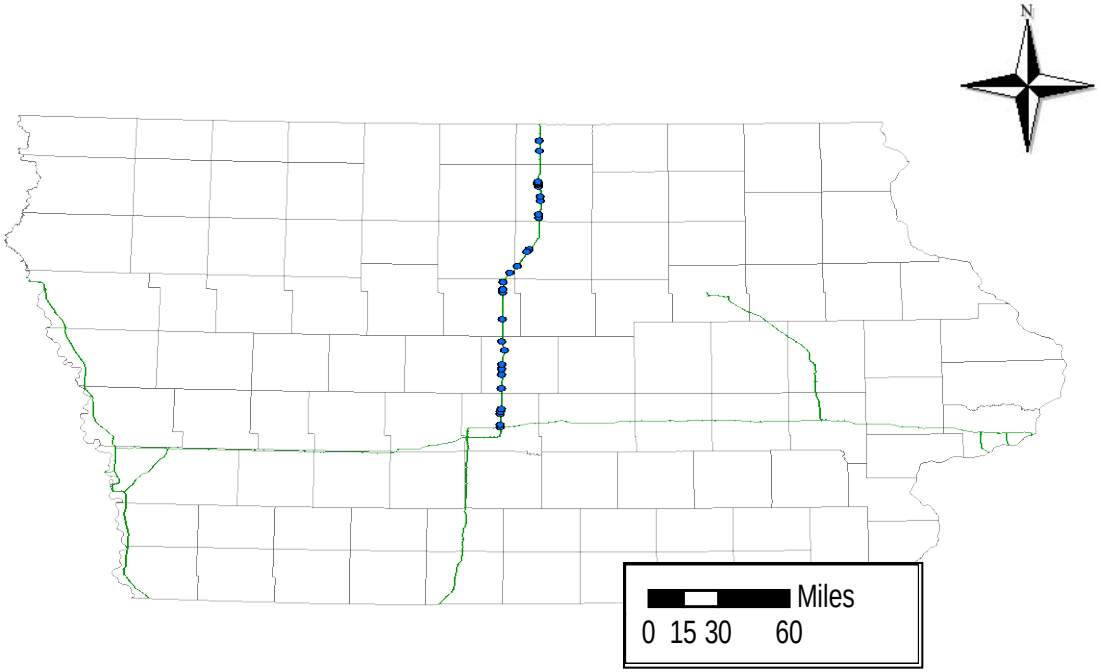
Disadvantages

- Requires knowledge (or educated guesses) of the condition of infrastructure to be evaluated
- No modeling capability – interdependency function not very well integrated

CARVER^2 – Bridge Assessment

- I-35 between Des Moines and the Iowa-Minnesota border.
- 30 bridges with 10,000 – 70,000 AADT.

Iowa Interstate-35 Bridges North of Interstate-80

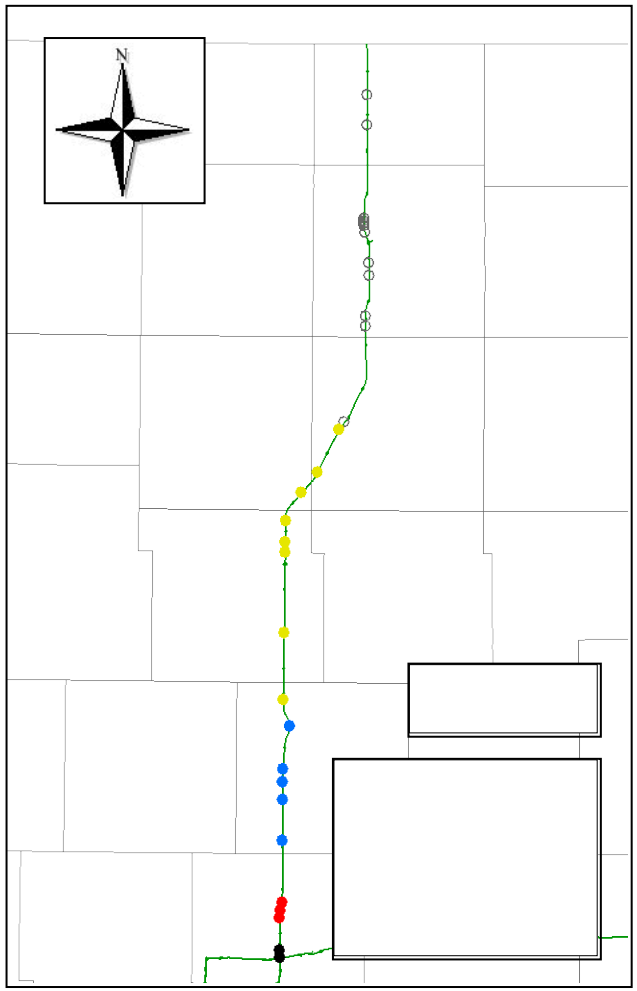


CARVER^2 – Likelihood Assessment

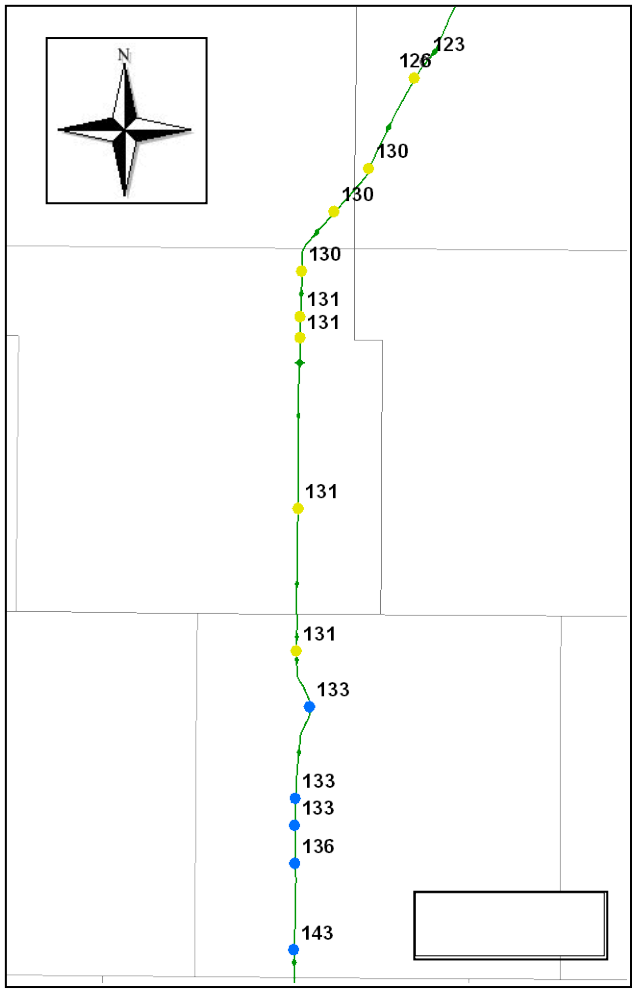
- Basic Data Input:
  - Affected Users: Use Iowa DOT AADT Counts
  - Direct Economic Loss & Rebuild Cost
    - Economic Loss scaled by AADT to similar events (e.g., I-35W bridge collapse).
    - Rebuild Cost based on similar bridge projects.
  - Fatalities: Use headways and assume occupancies to determine maximum number of people on bridge.
  - Recoverability: Determine rebuild time based on similar bridge projects.
  - Redundancy: Assumed that local roads can handle 50% of highway capacity, no access to road network information.

CARVER² – Results

Categorical Bridge Resiliency Ratings



Individual Bridge Resiliency Scores Snapshot



CARVER^2 – Interpreting Results

- Bridges increase in score from north to south
  - Reflects higher traffic levels, greater potential for severe disruption
  - Magnitudes of changes are not linear (e.g., going from a score of *116* to *126* vs. *166* to *176*)
- Effect of Redundancy: Need to balance additional traffic volume with additional capacity.
- Empirical justification for common-sense results.

CARVER^2 – Further Discussion

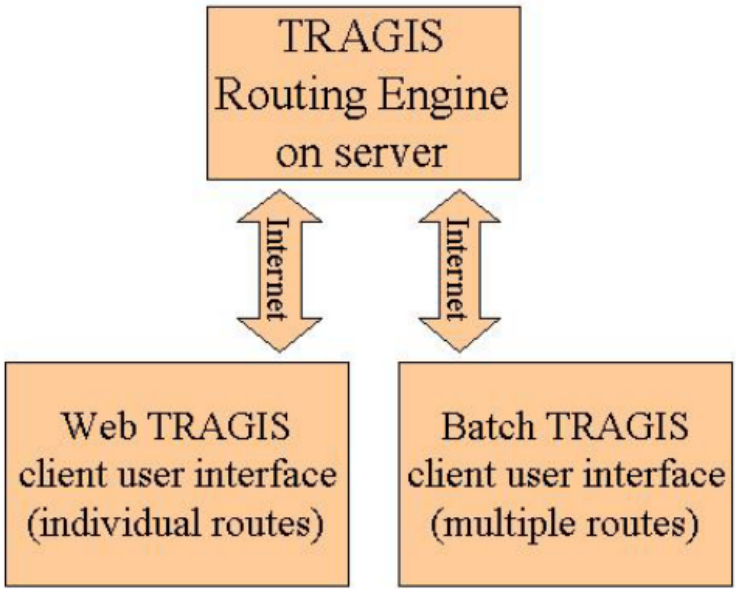
- Easy data input useful for non-technical assessments by government officials.
- Useful for Homeland Security-related assessments.
- Required data can easily be coded to draw from existing DOT and municipal asset databases as a way to generate snapshots of resiliency.

TRAGIS - Introduction

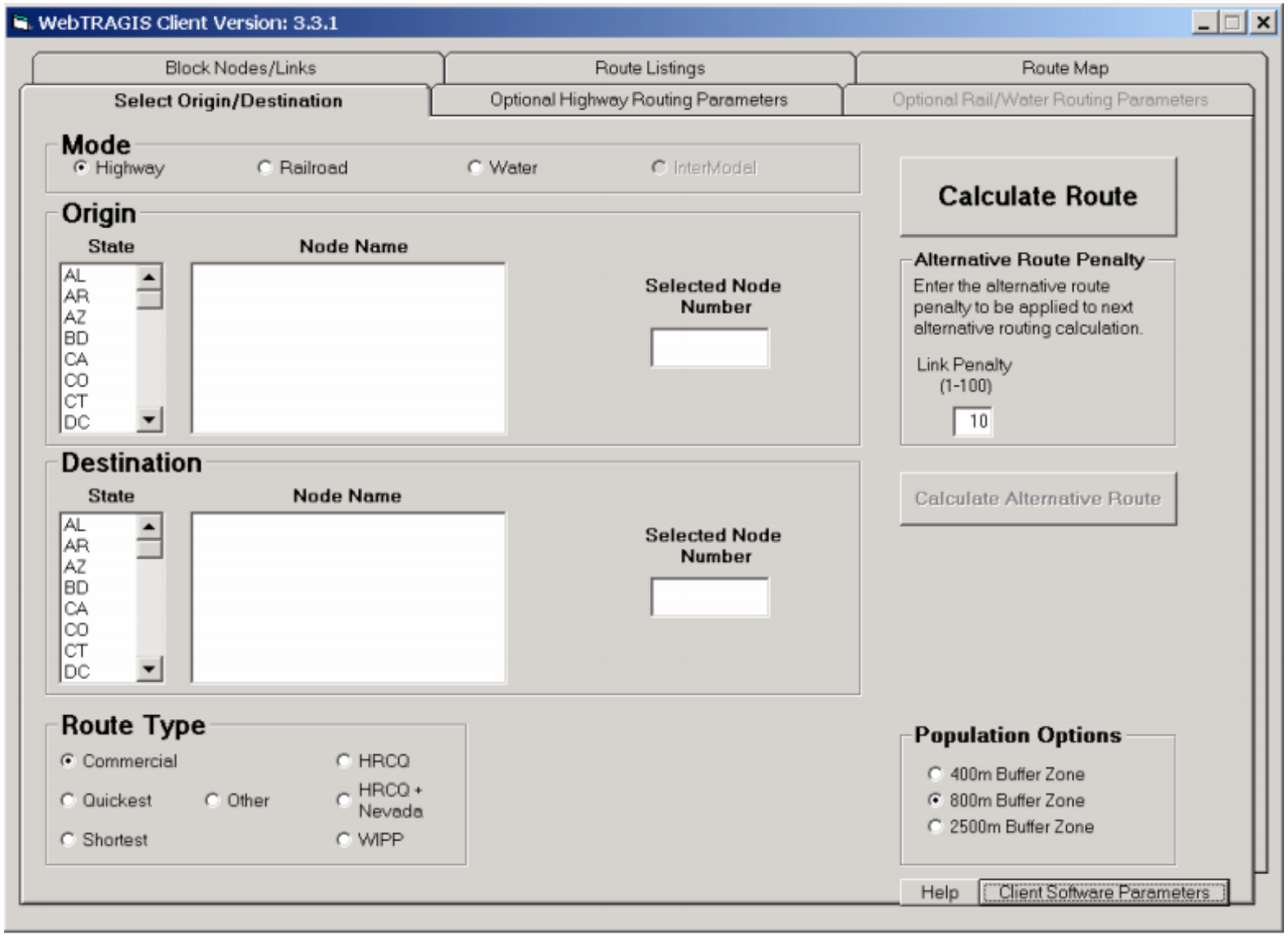
- **T**ransportation **R**outing **A**nalysis **G**eographic **I**nformation **S**ystem
- Developed by Oak Ridge National Laboratory, U.S. Department of Energy
- Most efficient geographic routing for highway, rail, and water
- Replaces HIGHWAY, INTERLINE models
- Current Availability
  - Currently undergoing updates & minor redesign
  - Expected to be completed later this year
  - Routing engine currently unavailable for use

TRAGIS – Conceptual Design

- User interface, map files reside on local computer
- Routing calculations, large data files reside on server
- Batch TRAGIS used for multilink network analysis
- Output is compatible with GIS software, such as ArcGIS
- Routing also includes population densities, for risk assessment



TRAGIS – User Interface



TRAGIS – Highway Routing

- Uses ORNL's National Highway Network
- 22,000 highway links, 16,000 nodes
- Includes all commercial nuclear plants, DOE sites, airports
- Minimize Impedance:

$$L = Min \sum_i (\alpha D_i + \beta T_i)$$

where

L = total impedance of a route;
α = distance bias;
D_i = distance of segment i, miles;
β = time bias;
T_i = time required to travel along segment i, minutes.

- Highway Route Controlled Quantity (HRCQ), Waste Isolation Pilot Plant (WIPP) also available for hazardous waste routing
- Similar networks for rail and waterways

TRAGIS – Rail Routing

- Contains data on track ownership by Class I, regional, and short line railroads
- 28,000 links, 24,000 nodes
- Nuclear reactor, DOE sites, military bases also included
- Impedance (commercial)
- TRAGIS tries to keep movements with the same railroad, on mainline track
- HRCQ routes also available

$$L = Min\left\{\sum_i \left(\sigma_i f_i d_i\right) + \sum_n \left(T_n\right)\right\},$$

L = total impedance of a route;
σ_i = railroad factor for link i, with
- $\sigma_i = 0.8$ for the originating railroad,
- $\sigma_i = 1.0$ for all other railroads;

f_i = mainline classification factor for link i, with
- $f_i = 1.0$ for A-mainline,
- $f_i = 1.2$ for B-mainline,
- $f_i = 1.9$ for A-branchline,
- $f_i = 4.0$ for B-branchline;

d_i = distance along link i, in miles;
T_n = transfer penalty factor at node n, with
- $T_n = 151.0$ for a terminal transfer,
- $T_n = 300.0$ for a primary transfer,
- $T_n = 400.0$ for a minor transfer,
- $T_n = 1500.0$ for a detour transfer.

TRAGIS – Water Routing

- Includes inland, coastal, and deep channel routes
- All ports, nuclear sites with barge facilities included
- Impedance
- Route accuracy needs

  be improved – not as granular as highway and rail networks

$$L = Min\left\{\sum_i \left(f_i d_i\right) + \sum_n T_n\right\}$$

L = total impedance of a route;
f_i = weighting factor for link i, with
f_i = 1.0 for deep water links, and
f_i = 1.5 for shallow water links;
d_i = distance for link i, in miles;
T_n = transfer penalty factor at node n.

TRAGIS – Node/Link Blocking

- TRAGIS allows the blocking of specific nodes, links, and even entire states
  - Useful for determining disruption impacts and for validating alternate routes in the event of construction, natural disasters, etc.
  - Additional restrictions available to route commercial vehicles
- With rail, railroad companies can also be blocked

TRAGIS – Population Density

- 400m, 800m, 2500m buffers available
  - Default 800m (~ ½ mi) buffer
- Based on LandScan USA grid cell database and 2000 census data
- Results can be exported as ESRI shapefile, or transferred directly to RADTRAN
- Rural, Suburban, and Urban weighted data available

WebTRAGIS Client Version: 3.3.1

Select Origin/Destination | Optional Highway Routing Parameters | Optional Rail/Water Routing Parameters

Block Nodes/Links | **Route Listings** | Route Map

Print | Save As | ReCalc Route | Route Info | Standard Listing | Standard and Pop Listing | Detailed Listing | Population Data Listing | Map Info | Error Log | Clear Output

```
TRAGIS Routing Engine Version 1.4.15       --  2000 Census Data

POPULATION DENSITY within   800 meter Buffer Zone:
FROM: DOE GERMANTOWN                MD    a
TO  : DOE FORRESTAL                 DC    G
-------------------------------------------------------------------------------

                  >0.0    22.7   59.7   139    326    821   1861   3326   5815
ST  MILES      0  -22.7  -59.7  -139   -326   -821  -1861  -3326  -5815  -9996  >9996
-------------------------------------------------------------------------------
DC    8.5   1.46  0.12   0.15   0.00   0.18   0.02   0.37   0.68   0.72   1.83   2.97
MD   19.4   0.00  0.06   0.19   0.27   0.73   1.93   2.47   4.59   5.05   2.71   1.43

TOTALS
     27.9   1.46  0.18   0.34   0.27   0.91   1.95   2.84   5.27   5.77   4.54   4.40
PERCENTAGES
            5.23  0.64   1.22   0.97   3.26   6.98  10.17  18.87  20.66  16.25  15.75

BASIS:   2000 Census data

RADTRAN Input Data       RURAL   SUBURBAN      URBAN
WEIGHTED POPULATION
People/sq. mi.            19.3     1714.3     7523.0
People/sq. km.             7.4      661.9     2904.6


DISTANCE                                              TOTALS
Miles                      2.3       11.0       14.7     27.9
Kilometers                 3.6       17.7       23.7     44.9
Percentages                8.1       39.3       52.7

BASIS (people/sq mi.)     <139   139-3326      >3326

Population within   800 meter Buffer Zone by State:
DC  73267  MD  65791

Total Population within   800 meter Buffer Zone:  139058
```

Help | Client Software Parameters

TRAGIS - Severity Assessment

- Use TRAGIS to determine alternative routings, assess travel time and distance impacts
- Generate estimates of users impacted by network interruptions
- Particularly useful for measuring impacts on commercial freight operations
- Scenarios for radioactive waste transport and disposal

TRAGIS - Network Disruption

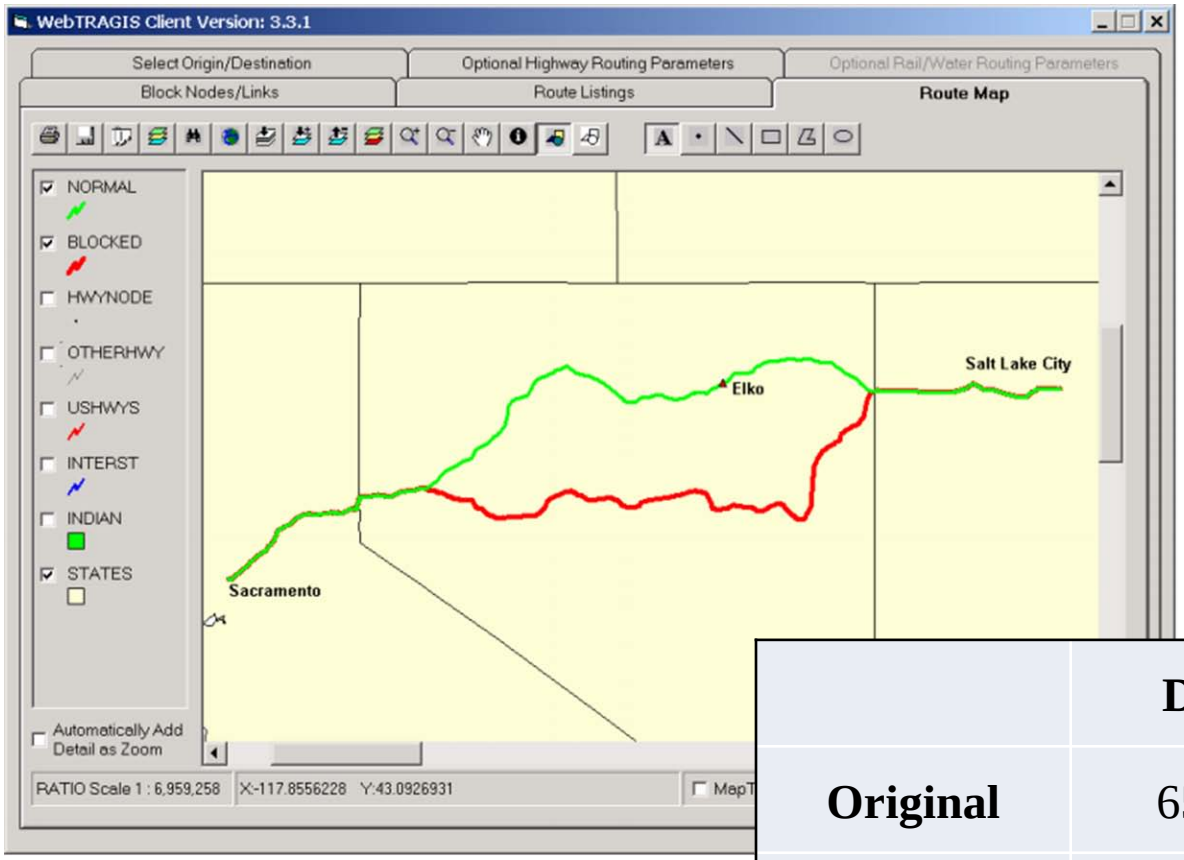
Sample Corridor: Salt Lake City, Utah to Sacramento, California

Event: Disruption of Interstate 80 near Elko, Nevada

- Natural Disaster
- Terrorist Attack

Result: Traffic re-routed to U.S. Highways 50 & 93 south of Elko

TRAGIS - Results



	Distance	Travel Time
Original	650 miles	9.3 hours
Revised	739 miles	11.3 hours
Net Increase	89 miles (14%)	2 hours (22%)

CARVER² & TRAGIS Conclusions

- Transportation resiliency: Uncertainty and risk management.
- A few tools exist to define resiliency in a planning context.
  - CARVER²: Easy-to-use database tool to generate basic comparisons of transportation resiliency and investment prioritization.
  - TRAGIS: Transportation routing tool that can be used to assess the impact of network disruptions.
- The use of software tools must be based on a comprehensive and consistent framework of resiliency planning.

Links to Software

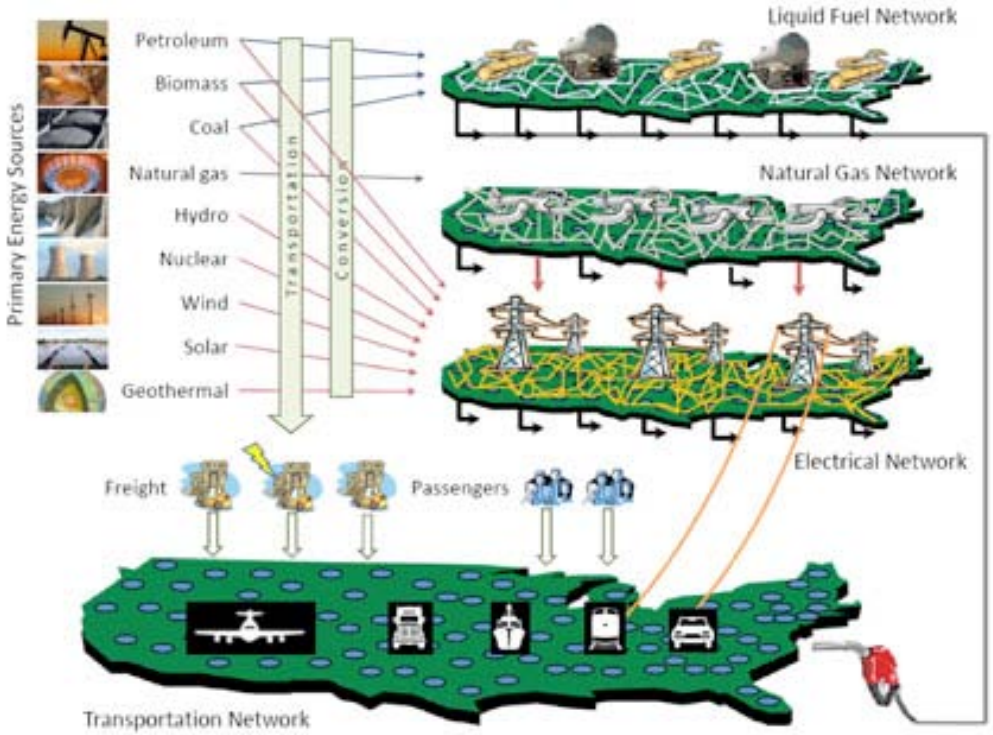
- CARVER^2
  - http://www.ni2cie.org/CARVER2.asp
  - Must sign usage agreement to gain access
  - Available for all government, non-profit, and educational agencies
- TRAGIS
  - https://tragis.ornl.gov/
  - Available for all non-commercial users
  - Must register and receive download link

Resiliency in a Broader Context

- CARVER2 and TRAGIS are fine for evaluating a corridor, or compiling a static list of areas for focus.
- How to dynamically consider large-scale systems?
- How do other infrastructures, such as the energy network, relate to transportation resiliency?

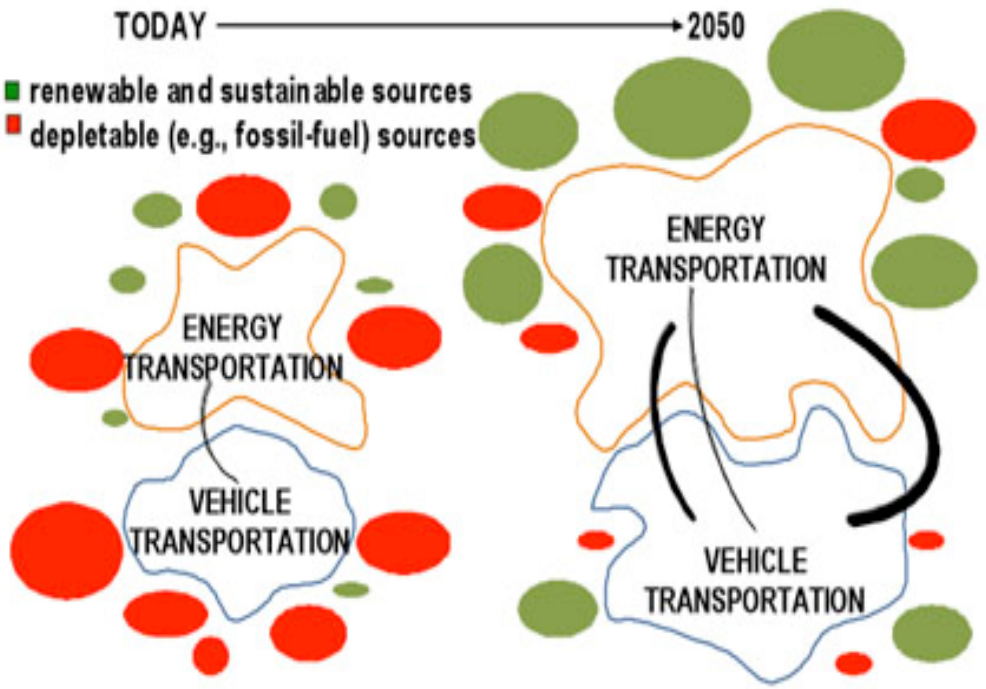
NETSCORE21

- **N**ational **E**nergy and **T**ransportation **S**ustainability, **Co**st, and **Re**siliency for the **21**st Century
- Identify long-term investment strategies for energy & transportation systems



NETSCORE Considerations

- Transportation
  - Highway, Conventional Rail, High-speed Rail, Waterway, Air
  - Passenger & Freight Movement
- Energy
  - Generation Technologies
  - Transmission & Storage



Data Development

- Passenger Data
  - National Household Travel Survey (NHTS)
  - Long-trips (>50 miles)
- Freight Data
  - Freight Analysis Framework v3
  - EIA Supplemental Information for Coal Commodities
- Operating & Investment Costs
  - Survey of State DOTs
  - Weighted according to Civil Works Construction Cost Index (CWCCI)
- Energy Use & Emissions
  - Energy Information Administration

Identifying Interdependencies

- Dual-derived demands
- Parallel paths to satisfy demand for electricity generation, transportation, or both.
- Effect on costs and prices of infrastructure investment
- Greenhouse gas emissions & pollutants
- Electric storage capability of PHEVs
- Competing/Complementary ROW needs

Project Deliverables

- NETSCORE21 will deliver a comprehensive vision of energy and transportation infrastructure investment policy.
- Netplan software
  - Multiobjective framework on pareto optimization front
  - Minimum cost solutions for transportation and energy investment
  - Able to model various scenarios that impact resiliency

Resiliency in NETSCORE21

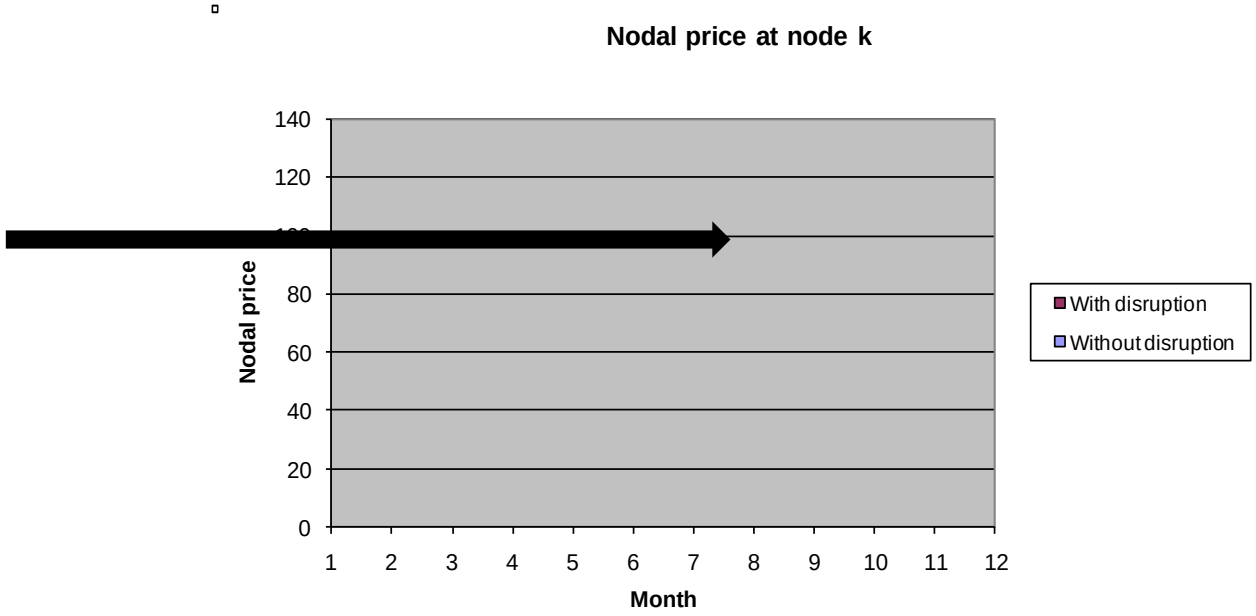
- Components: Robustness, Flexibility
- Goal: build a more resilient infrastructure:
  - To accommodate future needs & demands
  - Increase reliability
  - Promote diversity of modes
  - Contribute to economic development

Resiliency in NETSCORE21

Measure long-term resiliency in terms of price stability to high-impact events - sudden loss of

- **US Gulf natural gas supply,**
- **Powder River Basin coal,**
- **Middle Eastern oil,**
- **US uranium supply,**

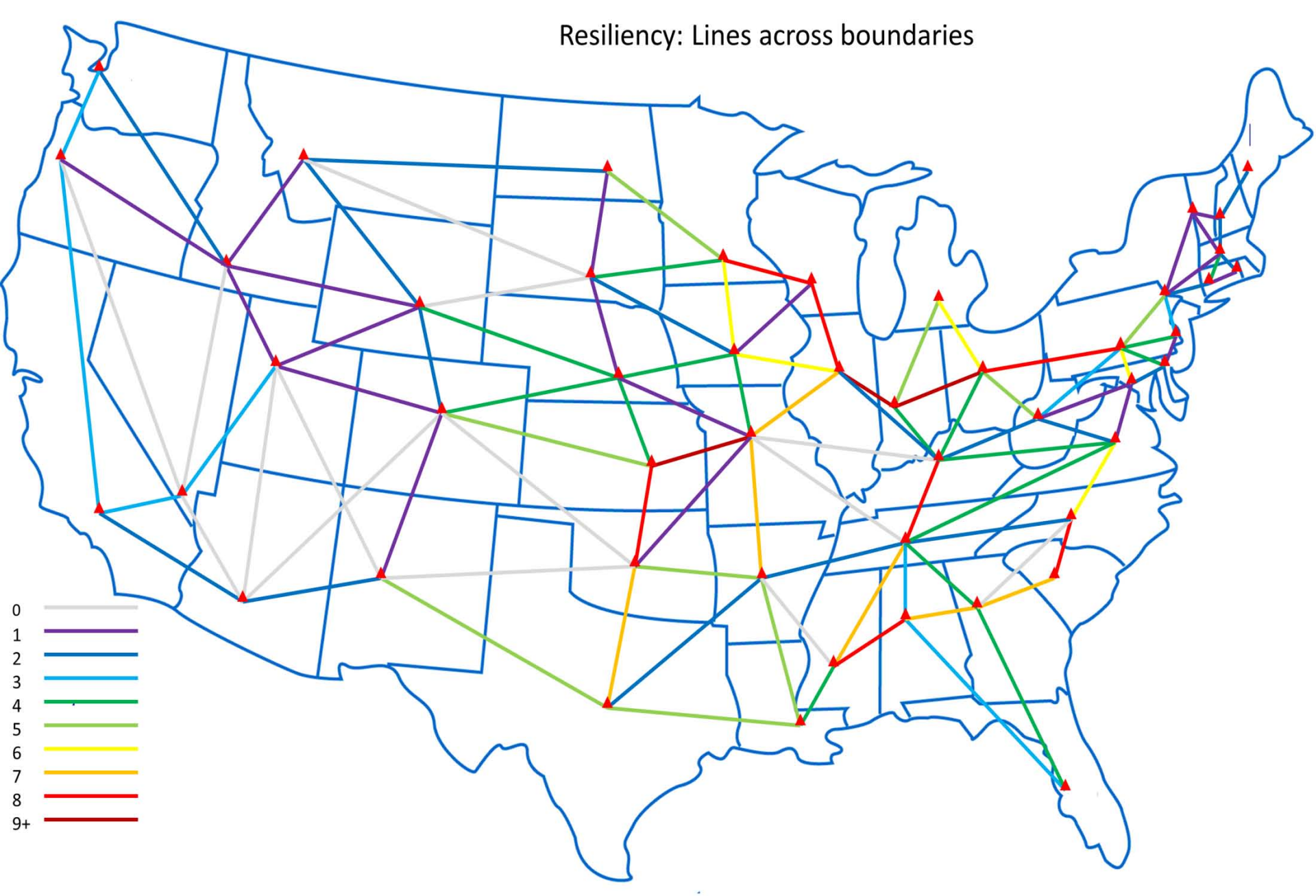
The time-integral of shadow price deviation with & without the 2005 Katrina/Rita impact



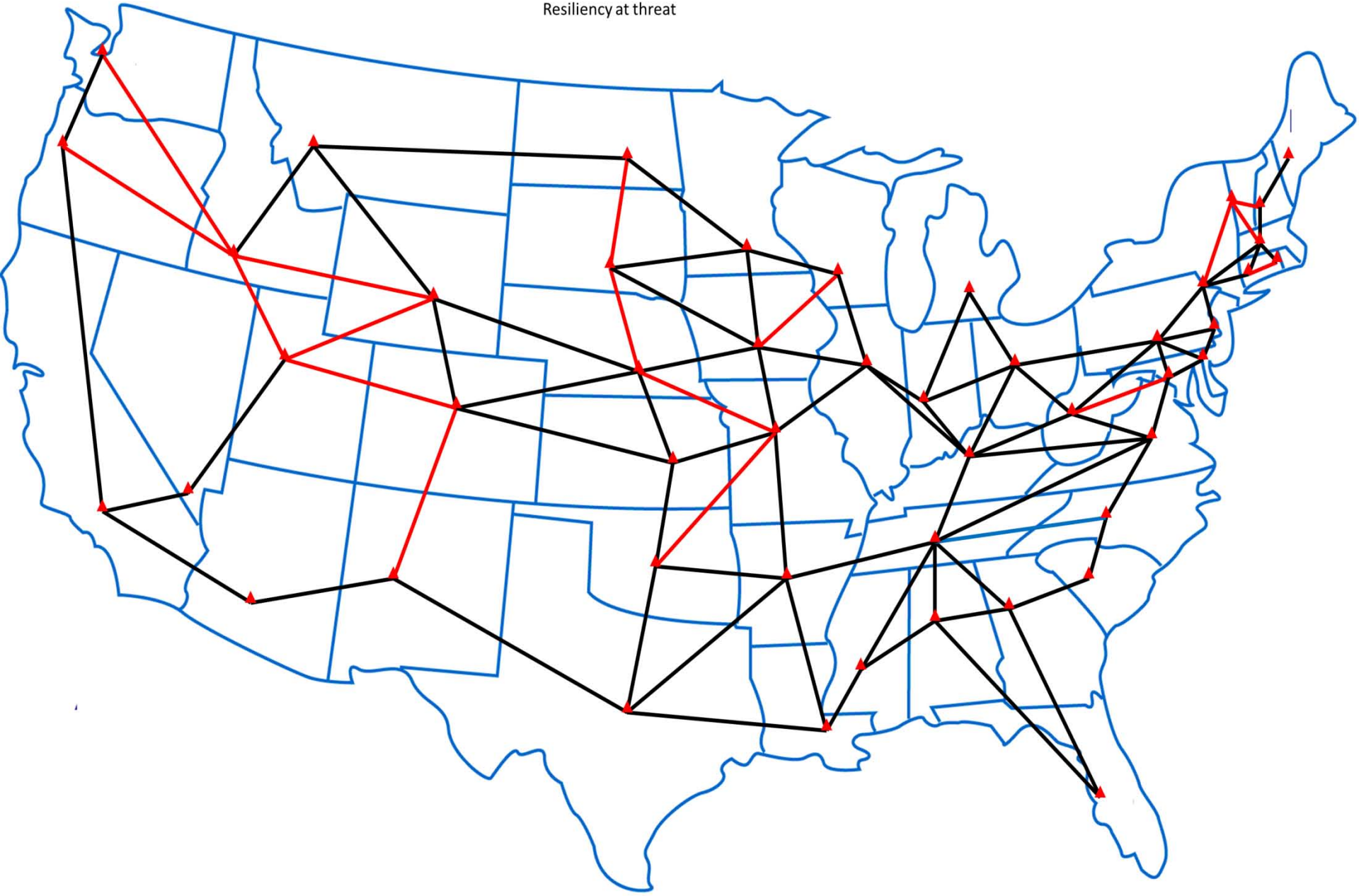
Other Resiliency Metrics

Robustness	Flexibility
Percent of unused network capacity, by mode	Dynamic messaging signs per miles of roadway
Number of alternate interstate routes, by mode	On-time performance/amount of delay
Miles of infrastructure per capita, by mode	Percentage of total demand shipped
Average time to return to full capacity	Average dollar amount lost per day due to network disruptions
Maintenance spending per capita/mile	

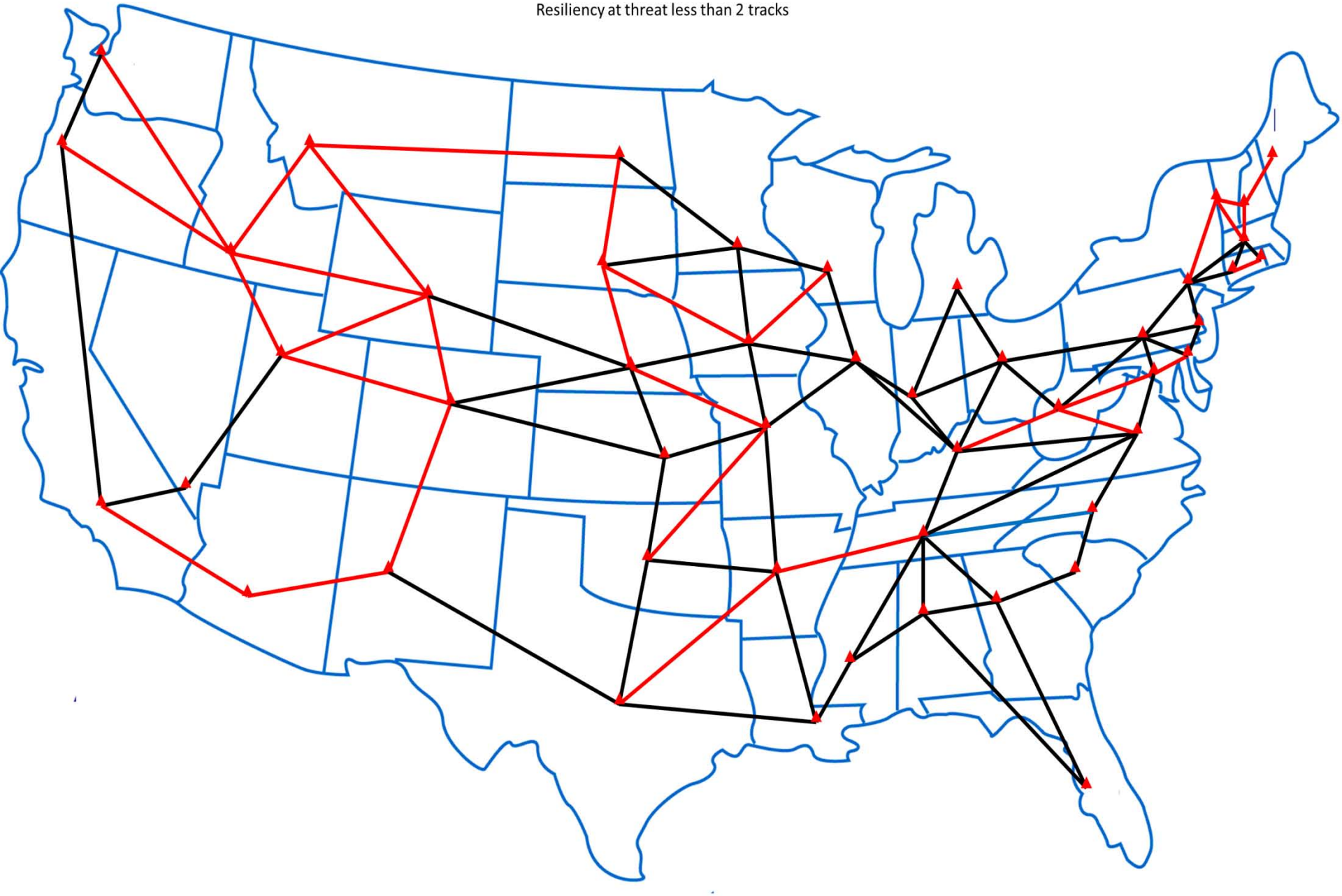
Resiliency: Lines across boundaries

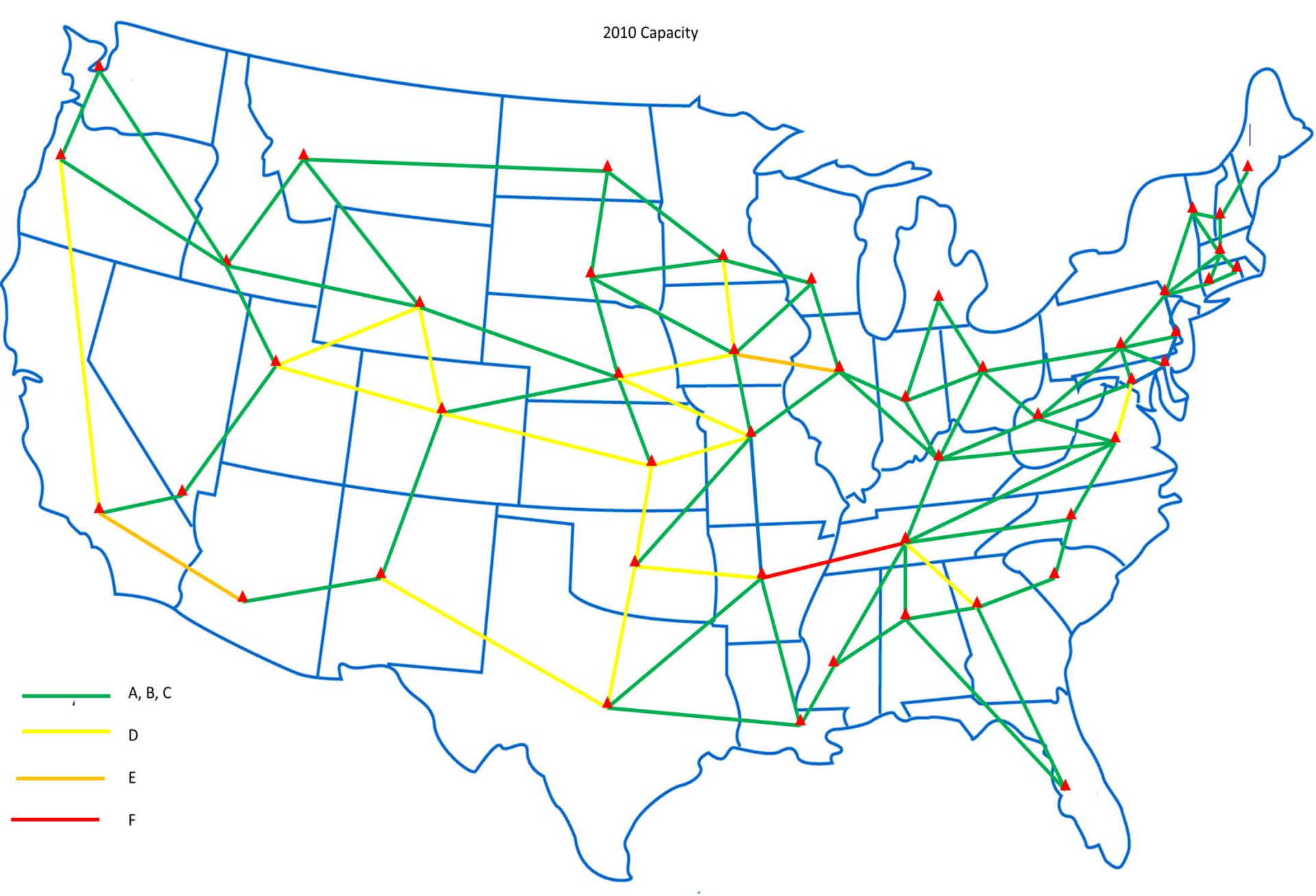


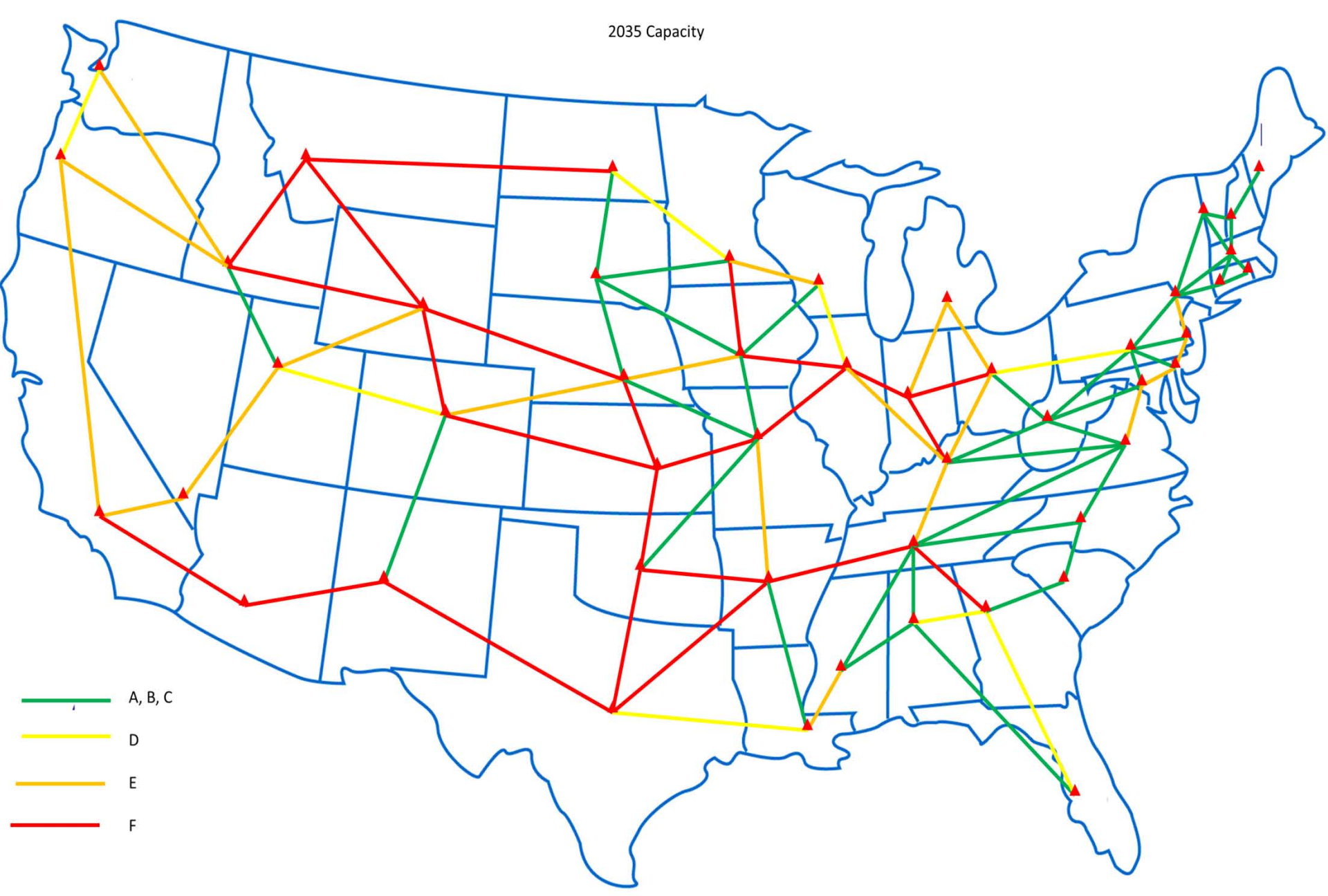
Resiliency at threat



Resiliency at threat less than 2 tracks




2010 Capacity
A, B, C
D
E
F


2035 Capacity
A, B, C
D
E
F

Modeling Challenges

- How to account for value of time in passenger transportation?
- Difficulties of passenger vs. freight transportation
- NTHS long-trips data is outdated
- Specific issues with Netplan topology (e.g., multi-link trip modal selection)

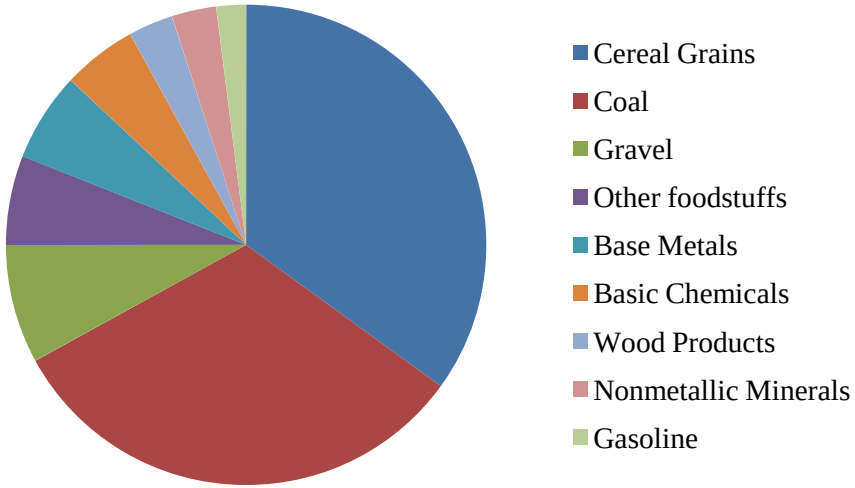
An Iowa Perspective…

- Why does a national modeling framework like NETSCORE21 matter for Iowa?
  - Goal of a statewide model for Iowa
  - Growing importance of alternative energy and biofuels
  - Impact of hybrid-electric vehicles and plug-in hybrids
- How do we convert a national model for use at the state level?

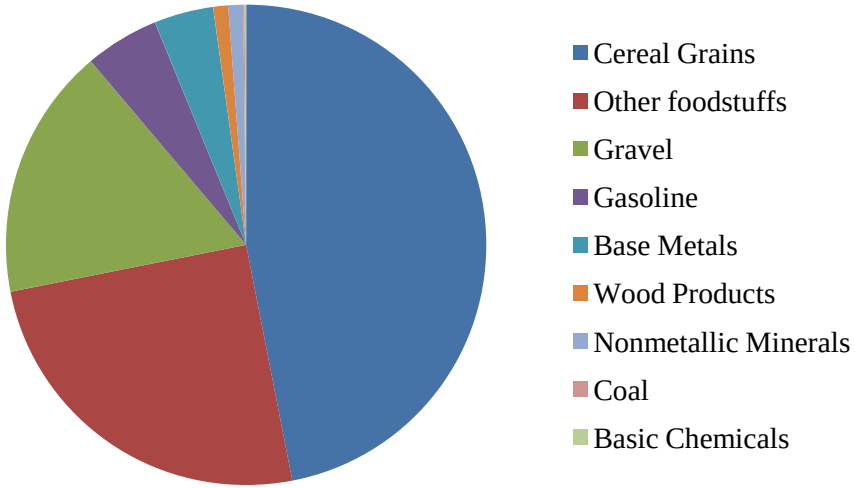
Iowa Transportation Statistics

- Freight Data
  - Destinations: MO, MI, MD, MA, TN
  - Origins: MO, MN, MS, MT, MI

Iowa Imports

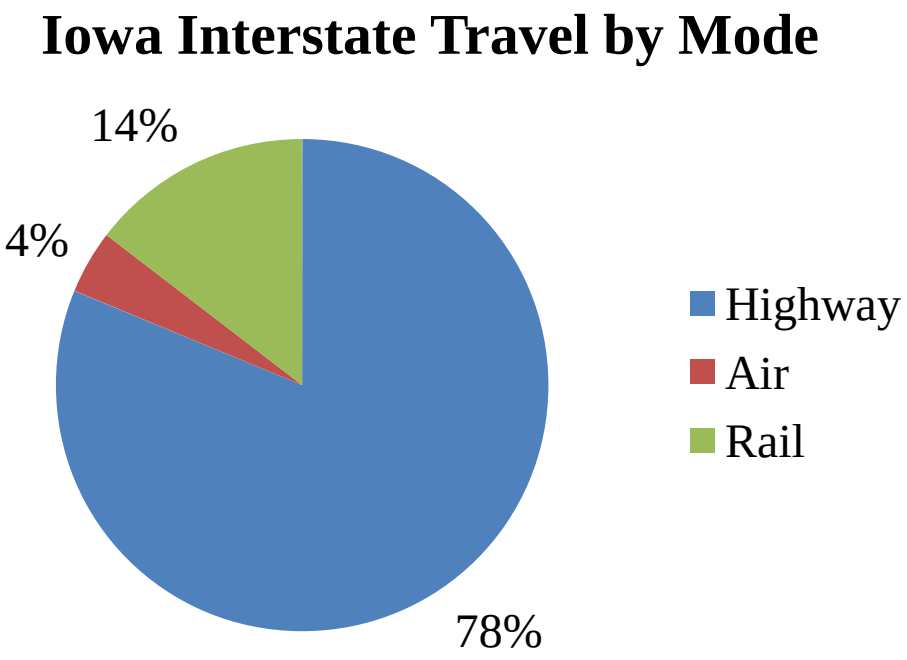


Iowa Exports



Iowa Transportation Statistics

- Passenger Data
  - Popular destinations: NE, MN, IL, SD, MO
  - Popular origins: IL, MN, MO, TX, OH



Netplan Questions for Iowa

- What will be the effect on long distance travel mode choice and cost for expanded intercity passenger rail?
- What impact on the demand for energy commodities (and their load on the transportation network) will expanded wind energy have?
- How will increasing use of biofuels and electricity impact energy use and travel patterns for vehicles in Iowa?
- Other questions?

Next Steps

- Finish developing full model for passenger and freight travel
- Incorporate waterway shipping as a freight mode
- Explore scenarios relating to high speed rail and alternative energy use
- Begin developing statewide model…

Thank You!