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\textsuperscript{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”

• Process Control: “The ability of a system to return to its original (or desired) state after being disturbed”

• Aerospace: “The ability to change when a force is enacted, and the ability to perform adequately while the force is in effect.”


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

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.”

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, publicly available (with restrictions)
CARVER$^2$ - Introduction

- Criticality, Accessibility, Recoverability, Vulnerability, Espyability, Redundancy, 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.

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CARVER² – User Interface

NI² Center for Infrastructure Expertise

CARVER²

SCORE: 143 - 4

Inspector: Default
Inspector: 
Organization: 
State or Municipality: 
Asset Name: Bridge 21
Address: 
Asset Identification Number: N/A
GPS: 
GIS: 
Sector: Transportation
Subtype: Bridges

Criticality
Impact of Loss of Asset
Users Affected: More than 25,000 People
Direct Economic Loss and Cost to Rebuild ($): Under 10 Million
Potential Deaths from Attack: 50

Accessibility
Ease at which terrorists can enter infrastructure to cause its destruction
Open to Public: 
Remote Site?: Yes

Recoverability
Time needed to replace infrastructure, if possible
More than 1 mo

Vulnerability
Susceptibility of infrastructure to destruction
Choose: Blast, Chem/Bio
Blast Attack: Concrete/Stone

Espyability
Is the infrastructure an "icon" representing more than a physical structure, i.e. national monument
(Notoriety): Locally Significant Non-Govt

Redundancy
Are there "back up" facilities/equipment that will offset the infrastructure loss
50%

Interdependency
Additional CI Sectors Affected by Loss of Asset
- Agriculture
- Food
- Water
- Public Health
- Emergency Services
- Government
- Defense Industry
- Information/Telecom
- Energy
- Bank Finance
- Chemical, Hazard Mat'
- Transportation
- Post Office, Shipping
- Icon

New  Save  Delete  Go to Record Number: 29 of 37  Go  Refresh  Record 29 of 37  

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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

• \(\text{Total Score} = \sum_{i=1}^{3} (\text{Criticality}_i + \text{Accessibility} + \text{Recoverability} + \text{Vulnerability} + \text{Espyability} - \text{Redundancy})\)

• 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
Iowa Interstate-35 Bridges North of Interstate-80

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

- **Transportation Routing Analysis Geographic Information System**
- 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:

\[ L = \text{Min} \sum_i (\alpha D_i + \beta T_i) \]

where
- \( L \) = total impedance of a route;
- \( \alpha \) = distance bias;
- \( D_i \) = distance of segment \( i \), miles;
- \( \beta \) = 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

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

- \( L \) = total impedance of a route;
- \( \sigma_i \) = 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

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

\( L \) = 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
<table>
<thead>
<tr>
<th>Print</th>
<th>Save As</th>
<th>ReCalc Route</th>
<th>Route Info</th>
<th>Standard Listing</th>
<th>Standard and Pop Listing</th>
<th>Detailed Listing</th>
<th>Population Data Listing</th>
<th>Map Info</th>
<th>Error Log</th>
<th>Clear Output</th>
</tr>
</thead>
</table>

**TRAGIS Routing Engine Version 1.4.15**

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**POPULATION DENSITY within 800 meter Buffer Zone:**

FROM: DUE GERMAN TOWN MD  a
TO: DUE FORRESTAL DC  b

<table>
<thead>
<tr>
<th>MILE</th>
<th>DC</th>
<th>MD</th>
<th>8.5</th>
<th>0.14</th>
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<th>0.37</th>
<th>0.60</th>
<th>0.72</th>
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<td>0.02</td>
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<td>0.60</td>
<td>0.72</td>
<td>1.03</td>
<td>2.97</td>
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<tr>
<td>19.4</td>
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**TOTALS**

<table>
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<tr>
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<th>0.37</th>
<th>0.60</th>
<th>0.72</th>
<th>1.03</th>
<th>2.97</th>
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<tbody>
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<td>27.9</td>
<td>1.46</td>
<td>0.18</td>
<td>0.34</td>
<td>0.27</td>
<td>0.91</td>
<td>1.95</td>
<td>2.84</td>
<td>5.27</td>
<td>5.77</td>
<td>4.54</td>
<td>4.40</td>
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</table>

**PERCENTAGES**

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<th>0.14</th>
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<th>0.15</th>
<th>0.00</th>
<th>0.08</th>
<th>0.02</th>
<th>0.37</th>
<th>0.60</th>
<th>0.72</th>
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<th>2.97</th>
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</thead>
<tbody>
<tr>
<td>5.23</td>
<td>0.64</td>
<td>1.22</td>
<td>0.97</td>
<td>3.26</td>
<td>6.98</td>
<td>10.17</td>
<td>18.87</td>
<td>20.66</td>
<td>16.25</td>
<td>15.75</td>
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</tbody>
</table>

**BASIS:**

2000 Census data

**RADTRAN Input Data**

<table>
<thead>
<tr>
<th>RURAL</th>
<th>SUBURBAN</th>
<th>URBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>People/sq.mi.</td>
<td>19.3</td>
<td>1714.3</td>
</tr>
<tr>
<td>People/sq.km.</td>
<td>7.4</td>
<td>661.9</td>
</tr>
</tbody>
</table>

**WEIGHTED POPULATION**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Miles</th>
<th>Kilometers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles</td>
<td>2.3</td>
<td>3.6</td>
<td>8.1</td>
</tr>
<tr>
<td>Kilometers</td>
<td>11.0</td>
<td>17.7</td>
<td>39.3</td>
</tr>
<tr>
<td>Percentages</td>
<td>14.7</td>
<td>23.7</td>
<td>52.7</td>
</tr>
</tbody>
</table>

**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: 139050

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Help  Client Software Parameters
• 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

<table>
<thead>
<tr>
<th></th>
<th>Distance</th>
<th>Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original</strong></td>
<td>650 miles</td>
<td>9.3 hours</td>
</tr>
<tr>
<td><strong>Revised</strong></td>
<td>739 miles</td>
<td>11.3 hours</td>
</tr>
<tr>
<td><strong>Net Increase</strong></td>
<td>89 miles (14%)</td>
<td>2 hours (22%)</td>
</tr>
</tbody>
</table>
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$^2$
  – Must sign usage agreement to gain access
  – Available for all government, non-profit, and educational agencies

• TRAGIS
  – [https://tragis.ornl.gov/](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?
• National Energy and Transportation Sustainability, Cost, and Resiliency for the 21st 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.
<table>
<thead>
<tr>
<th>Robustness</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of unused network capacity, by mode</td>
<td>Dynamic messaging signs per miles of roadway</td>
</tr>
<tr>
<td>Number of alternate interstate routes, by mode</td>
<td>On-time performance/amount of delay</td>
</tr>
<tr>
<td>Miles of infrastructure per capita, by mode</td>
<td>Percentage of total demand shipped</td>
</tr>
<tr>
<td>Average time to return to full capacity</td>
<td>Average dollar amount lost per day due to network disruptions</td>
</tr>
<tr>
<td>Maintenance spending per capita/mile</td>
<td></td>
</tr>
</tbody>
</table>
Resiliency at threat
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
- Cereal Grains
- Coal
- Gravel
- Other foodstuffs
- Base Metals
- Basic Chemicals
- Wood Products
- Nonmetallic Minerals
- Gasoline

Iowa Exports
- Cereal Grains
- Other foodstuffs
- Gravel
- Gasoline
- Base Metals
- Wood Products
- Nonmetallic Minerals
- Coal
- Basic Chemicals
• Passenger Data
  – Popular destinations: NE, MN, IL, SD, MO
  – Popular origins: IL, MN, MO, TX, OH

Iowa Interstate Travel by Mode

- Highway: 78%
- Air: 4%
- Rail: 14%
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!