Planning Tools for Evaluating Transportation Network Resiliency

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Overview of Topic

• Definitions of Resiliency
  – General Definition
  – Transportation Context

• CARVER²
  – General program description & usage
  – Example: Bridge assessment

• TRAGIS
  – General program description & usage
  – Example: Route closure
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.”

CARVER² - Introduction

• Criticality Accessibility Recoverability Vulnerability Espyability Redundancy, version 2
• Developed by NI² 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.
# CARVER\textsuperscript{2} – User Interface

## CARVER\textsuperscript{2} – NI\textsuperscript{2} Center for Infrastructure Expertise

### Inspector
- Default
- Inspector

### Organization
- State or Municipality

### Asset Name
- Bridge 21

### Asset Identification Number
- N/A

### Address
- 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

### Recoverability
- Time needed to replace infrastructure, if possible

### Vulnerability
- Susceptibility of infrastructure to destruction
  - Choose: Blast, Chem/Bio

### 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

### Interdependency
- Additional CI Sectors Affected by Loss of Asset

## Record Details

- **Record:** 29 of 37
- **Score:** 143 – 4
- **New**
- **Save**
- **Delete**
- **Go to Record Number**
- **Go**
- **Refresh**

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**Iowa State University**

**Institute for Transportation**

[www.intrans.iastate.edu](http://www.intrans.iastate.edu)
CARVER² – 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** = 
  \[ \sum_{i=1}^{3} \text{Criticality}_i + \text{Accessibility} + \text{Recoverability} + \text{Vulnerability} + \text{Espyability} - \text{Redundancy} \]

- 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\textsuperscript{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
CARVER² – Bridge Assessment

- I-35 between Des Moines and the Iowa-Minnesota border.
- 30 bridges with 10,000 – 70,000 AADT.
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.
CARVER$^2$ – 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

- **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
• 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 – 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:
  \[ L = \min \sum_i \left( \alpha D_i + \beta T_i \right) \]

  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 – 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
### TRAGIS Routing Engine Version 1.4.15

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**2000 Census Data**

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

<table>
<thead>
<tr>
<th>FROM: DUE GERMANTOWN</th>
<th>TO: DUE FORRESTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>DC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MILES</th>
<th>22.7</th>
<th>59.7</th>
<th>-326</th>
<th>821</th>
<th>1061</th>
<th>3326</th>
<th>5815</th>
<th>9996</th>
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</thead>
<tbody>
<tr>
<td>DC</td>
<td>1.46</td>
<td>0.12</td>
<td>0.15</td>
<td>0.00</td>
<td>0.18</td>
<td>0.02</td>
<td>0.37</td>
<td>0.60</td>
</tr>
<tr>
<td>MD</td>
<td>19.4</td>
<td>0.00</td>
<td>0.06</td>
<td>0.19</td>
<td>0.27</td>
<td>0.73</td>
<td>1.93</td>
<td>2.47</td>
</tr>
</tbody>
</table>

**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

**R&TRAN Input Data**

<table>
<thead>
<tr>
<th>RURAL</th>
<th>SUBURBAN</th>
<th>URBAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.3</td>
<td>1714.3</td>
<td>7523.0</td>
</tr>
<tr>
<td>7.4</td>
<td>661.9</td>
<td>2904.6</td>
</tr>
</tbody>
</table>

**WEIGHTED POPULATION**

- People/sq. mi.: 19.3, 1714.3, 7523.0
- People/sq. km.: 7.4, 661.9, 2904.6

**DISTANCE**

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

**TOTALS**

| 27.9 | 34.9 | 44.9 |

**BASIS (people/sq mi.):**

<table>
<thead>
<tr>
<th>&lt;139</th>
<th>139-3326</th>
<th>&gt;3326</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Population within 800 meter Buffer Zone by State:**

- DC: 73267
- MD: 65791

**Total Population within 800 meter Buffer Zone:**

139050
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
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>Original</td>
<td>650 miles</td>
<td>9.3 hours</td>
</tr>
<tr>
<td>Revised</td>
<td>739 miles</td>
<td>11.3 hours</td>
</tr>
<tr>
<td>Net Increase</td>
<td>89 miles (14%)</td>
<td>2 hours (22%)</td>
</tr>
</tbody>
</table>
Conclusion

• Transportation resiliency: Uncertainty and risk management.

• Numerous 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