Improving Transportation Infrastructure System Resilience Using Federal Tools and Customized Models

Dr. Silvana V Croope


January 13, 2013
Discussion topics

- Ph.D. research: Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge

- An approach to resilience

- The need for Decision Support Models and Tools to promote critical transportation infrastructure protection

- Loss estimation models and tools

- Conclusion
Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - I

USGS, presidential disaster declarations, flooding 1965 to 2003.


Disruption of essential services
Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - II

- Operations and management nature
- Data and tools needed to support decision making
- Failure/degraded operations and performance consequences

Objectives
- Mitigate CIS failure, disruption, and damage
- Promote better physical conditions for systems to work
- Ensure continuity of flow of people and goods

Factors

Tools

CIR-DSS Framework

Geographical context,
Civil infrastructure systems analysis (asset management systems),
Vulnerability and impact assessment
CIR-DSS Framework

Disaster Cycle

Disaster Timeline for CIR-DSS

Assess Risk (Vulnerability), failure and system resilience

Disaster Occurs

Mitigation

Response

Recovery

Assess Damage, define priorities, funds, and system improvement (alternative project)

Results Comparison

OUTCOMES
- e.g. local impact with few loss of lives (risk), common cause (failure), not redundant (resilience)

OUTCOMES
- e.g. destroyed bridges, “medium” traffic flow, federal threshold met, bridges rebuilding

CIS improvement

PLANS

Actions

Repair
Rebuild
Redevelopment (New)

Maintenance
Rehabilitation
Redevelopment (New)
Decision-Making – CIR-DSS Macro Environment

- Selection of course of action from possibilities
- Benefit, risk, alternatives (do nothing to implement)
- Process/method to analyze a structured problem through a hierarchy organization
- Focus on resilience of system problem solutions
- Large number of variables
Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - III

- Manage infrastructure and ensure transportation functionality by
  - Evaluating component or system failures & vulnerabilities
  - Changing vulnerability of networked systems evaluation
  - Changing cause of failure – use exceeding capacity or negative interactions
Resilience (network)

- System’s ability to provide and maintain an acceptable level of service when facing faults and challenges to its normal operation

- System’s ability to recover/restore itself to former conditions or, adaptive capacity

- Resilience metrics
  - performance indicators,
  - safety measures, and/or
  - rating systems capturing systems behavior
Loss Estimation Approach - GIS

- **Vulnerability** - measure of susceptibility to suffer loss or damage.
  - Human product of physical exposure to a disaster resulting in some degree of loss, considering human capacity to withstand, prepare for, and recover from disasters.

[Map of Seaford Interest Area Rain Precipitation]

[Map of Seaford Study Area Elevation Evaluation]

Seaford, Sussex County, DE
Loss Estimation - GIS for Assessing Resilience

Location of Damaged Infrastructure in the Seaford Flooded Area

Seaford Road Network and Detours Analysis
Federal Official standardized software for loss estimation and impact assessment

Provides organizing principle and an analytical capabilities
- Qualitative and Quantitative

Uses official organizations for collecting data, building basic inventory and mathematical functions

Works with 3 Levels for Analysis

Is constantly being updated and building more in depth analysis capability
HAZUS-MH for CIR-DSS

Study Region: Seaford Case Study
Description: In June 25, 2006 Delaware had a Federal Disaster Declaration
Scenario: Annual_Losses
HAZUS-MH Analyses for CIR-DSS

“What if” Levee Protection Scenario

“What if” Flow Regulation Scenario

Floodwater Velocity Estimation Scenario

Damage related to US13 in Sussex County
### Transportation System Dollar Exposure

**October 27, 2008**

All values are in thousands of dollars.

<table>
<thead>
<tr>
<th>Delaware</th>
<th>Highway</th>
<th>Railway</th>
<th>Light Rail</th>
<th>Bus Facility</th>
<th>Ports</th>
<th>Ferries</th>
<th>Airport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sussex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segments</td>
<td>205,419.68</td>
<td>31,130.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>67,754.40</td>
<td>304,304.08</td>
</tr>
<tr>
<td>Bridges</td>
<td>14,754.85</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>14,754.85</td>
</tr>
<tr>
<td>Tunnels</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Facilities</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1,188.10</td>
<td>0.00</td>
<td>0.00</td>
<td>5,940.50</td>
<td>7,128.60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>220,174.53</td>
<td>31,130.00</td>
<td>0.00</td>
<td>1,188.10</td>
<td>0.00</td>
<td>0.00</td>
<td>73,694.90</td>
<td>326,187.53</td>
</tr>
</tbody>
</table>

**Debris Summary Report**

**October 27, 2008**

All values are in tons.

<table>
<thead>
<tr>
<th>Delaware</th>
<th>Finishes</th>
<th>Structures</th>
<th>Foundations</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sussex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,709</td>
<td>323</td>
<td>765</td>
<td>2,797</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,709</td>
<td>323</td>
<td>765</td>
<td>2,797</td>
</tr>
<tr>
<td>Scenario Total</td>
<td>1,709</td>
<td>323</td>
<td>765</td>
<td>2,797</td>
</tr>
</tbody>
</table>
HAZUS-MH Assessment Summary

- Enables comparison of some mitigation alternatives

### Global Summary for Annual Loss

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Exposure ($1000)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>307,736</td>
<td>72.7%</td>
</tr>
<tr>
<td>Commercial</td>
<td>89,543</td>
<td>21.1%</td>
</tr>
<tr>
<td>Industrial</td>
<td>12,150</td>
<td>2.9%</td>
</tr>
<tr>
<td>Agricultural</td>
<td>1,515</td>
<td>0.4%</td>
</tr>
<tr>
<td>Religion</td>
<td>7,296</td>
<td>1.7%</td>
</tr>
<tr>
<td>Government</td>
<td>3,098</td>
<td>0.7%</td>
</tr>
<tr>
<td>Education</td>
<td>2,248</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>423,586</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

### Global Summary for Single Return Period - Levee

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Exposure ($1000)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>319,933</td>
<td>74.2%</td>
</tr>
<tr>
<td>Commercial</td>
<td>85,604</td>
<td>19.9%</td>
</tr>
<tr>
<td>Industrial</td>
<td>12,221</td>
<td>2.8%</td>
</tr>
<tr>
<td>Agricultural</td>
<td>1,645</td>
<td>0.4%</td>
</tr>
<tr>
<td>Religion</td>
<td>7,213</td>
<td>1.7%</td>
</tr>
<tr>
<td>Government</td>
<td>2,286</td>
<td>0.5%</td>
</tr>
<tr>
<td>Education</td>
<td>2,248</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>431,150</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>
CIR-DSS Model Framework

GIS + HAZUS-MH

CIR-DSS Model Insight in STELLA

Step 1: getting local infrastructure information - data
Step 2: Initial Local Infrastructure System Performance Measures
Step 3-4: degrading system performance due to disaster, Transitional System Performance Measures
Step 5-7: improving system performance, Improved System Performance Measures
Step 8: system resilience decision, implementation or do nothing

Stella – system dynamics software
### STELLA Analyses Step Example

- **US13 assessment values assumption:**
  - Percentage based on totals from the highway network cost / US13 cost (34.60%)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>205,419,000.6</td>
<td>220,174,000.5</td>
<td>3,000,000.00</td>
<td>341,888.00</td>
</tr>
<tr>
<td>71,079,000.02</td>
<td>76,180,387.38</td>
<td>1,038,000.00</td>
<td>118,293.25</td>
</tr>
</tbody>
</table>

### Study Area US13 Infrastructure (US$ in Thousands)

<table>
<thead>
<tr>
<th>OBJECTID</th>
<th>ID</th>
<th>Name</th>
<th>Length</th>
<th>Traffic</th>
<th>Cost</th>
<th>NumLanes</th>
<th>Pavement</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>DE000060</td>
<td>Sussex Hwy</td>
<td>10.83</td>
<td>0</td>
<td>$32,206.20</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>5</td>
<td>DE000066</td>
<td>Sussex Hwy</td>
<td>0.88</td>
<td>0</td>
<td>$2,628.59</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>6</td>
<td>DE000068</td>
<td>Sussex Hwy</td>
<td>2.54</td>
<td>0</td>
<td>$7,543.82</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>7</td>
<td>DE000069</td>
<td>Sussex Hwy</td>
<td>0.33</td>
<td>0</td>
<td>$987.21</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>8</td>
<td>DE000085</td>
<td>United States Highway</td>
<td>3.62</td>
<td>0</td>
<td>$21,534.23</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>21</td>
<td>DE000509</td>
<td>United States Highway</td>
<td>0.77</td>
<td>0</td>
<td>$4,555.43</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>22</td>
<td>DE000511</td>
<td>United States Highway</td>
<td>0.27</td>
<td>0</td>
<td>$1,623.54</td>
<td>4</td>
<td>0.7</td>
<td>9600</td>
</tr>
<tr>
<td>Probability of a 100-year storm event in the case study area</td>
<td>Result of: (Recovery projects - Mitigation projects)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>-9809 recovery cost less than mitigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4%</td>
<td>44065 recovery cost more than mitigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>115896 recovery cost more than mitigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

↑ frequency of the 100-year storm event

↑ worthwhile investments in mitigation projects
Complex system modeling required many assumptions and models to capture changes over time.

Data from many sources were used as input into the model.

Comprehensive development offers insights into tradeoffs and opportunities to capture damage and costs in the context of resiliency.

Framework and model can be scalable.

Model can benefit from refinements to operationalize this approach.
Aknowledgements

- DelDOT
- Dr. Sue McNeil
- FEMA – Hazus Program and Risk Analysts Officials