INTEGRATING HAZUS-MH DATA AND OUTPUTS TO A DECISION SUPPORT SYSTEM

Silvana V Croope, PhD

HAZUS User Group Topic Specific Call
02/15/2011
BUILDING BLOCKS

- A complex problem to research
- Critical Infrastructure Resilience Decision Support System (CIR-DSS)
- Spatial Decision Support System (SDSS)
  - The Case Study
  - SDSS: GIS + HAZUS-MH analyses
  - SDSS Benefits and Limitations
- HAZUS-MH Data and Analyses Integration to CIR-DSS
  - Inventory and analyses results from HAZUS
  - Summary of processes integrating HAZUS data and analyses results
  - Case Study results summary
- Future Work with HAZUS-MH and Expected Benefits
A COMPLEX PROBLEM TO RESEARCH

- Limited Resources for Infrastructure Improvement/Repair/Replacement
  - Aging Infrastructure
  - M, R & R challenges
- Increasing Awareness of Catastrophic Failure
  - Katrina 2005
  - DelDOT/TMC – Seaford/DE 2006
- Evidence of increasing threats, e.g.
  - Terrorists (9/11/2001)
  - Storms due to climate change
CIR-DSS FRAMEWORK

- What if scenario (e.g.)

Assess Risk (Vulnerability), failure and system resilience

Disaster Occurs

Mitigation

Response

Recovery

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

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

Results Comparison

ACTIONS ...
Objective: *To improve the resilience of critical infrastructure systems*

- Decision variables – To undertake mitigation
- Other variables

Resilience metrics: capacity, pavement condition, level of service

Net present value of costs and costs avoided
- Recovery and versus Mitigation
System Dynamics Diagram of Decision Support System for Critical Infrastructure System Resilience (CISR)

- **SDSS**
  - GIS Software (e.g. ArcInfo)
- **Critical Infrastructure**
  - **Physical Subsystem**
  - **Administration Subsystem**
- **Geographic Dimension**
- **Disaster Type, Characteristics/Data and Trends**
- **Analysis Tools/Extensions**
- **Decision Support System**
  - Decision Support Information (Knowledge Base)
  - Time Frame and Post-Disaster Phase (Data)
  - Insight for Resilience-Based Decision Making
  - Result Presentation System
- **Critical Infrastructure Management System**
  - Functional Subsystem – Asset Management
  - Decision Making Subsystem
  - CISR Decision-Making Organizations
  - CISR Decisions
- **Financial Subsystem**

**Critical Infrastructure Management System**
- Decision Problems – requirements & constraints

**CISR Decision Support System**
DATA AND ANALYSIS FOR DECISION MAKING

DATA NEEDS (LOCAL)

- Geographic: hydrology, elevation
- Hazard: weather, disaster history records and trends
- Infrastructure: roads, bridges
- Financial: cost of infrastructure
- Institutional/cultural: decision-makers, policies and funding
- Infrastructure life-cycle
- Expected infrastructure life-cycle with mitigation

ANALYSES/ASSESSMENTS

- Vulnerability, Risk/Impact and Damage Analysis
- Pre-, During and Post-Event Assessment – infrastructure condition and performance
- Mitigation Strategies (definition)
- Pre-, During and Post-Event Resilience Assessment
- Cost-Benefit Analysis
- Recovery and Mitigation Strategies Comparison
- Scenarios Test/Evaluation
CASE STUDY: DELAWARE FLOODING – JUNE 2006

Federal Disaster Declarations 1965-2003: Sussex County – DE

1 FDD
2 FDD
3 FDD
4 or more FDD
DATA SOURCES AND TOOLS

MAIN DATA SOURCES

- DelDOT Transportation Management Center: pictures, traffic and detours reports (DelDOT Officials)
- DelDOT Bridge Management: bridge data (GIS), reports of local damaged bridges, digital maps (pdf) (DelDOT Officials)
- DelDOT (others): roads, State boundaries
- Spat Lab (U.D.): Elevation Data
- DataMIL: roads, rivers, hydrology, municipal boundaries
- Delaware Environmental Observing System (DEOS): radar derived rainfall
- HAZUS-MH MR3 inventory
- Literature

TOOLS

- GIS ArcInfo and extensions
  - Spatial Analyst
  - Network Analyst
- Excel
- HAZUS-MH MR3
  - Flood Model
  - Analysis Level 1
- STELLA®
Specific locations issues – spatial data and local infrastructure

Complex problems structuring to support decision-making processes

Does not replace users’ decision-making

Easiest data and information sharing/integration (further analyses)

Analysis outputs help support decisions for infrastructure repair, improvement and mitigation

System Dynamics Diagram of Decision Support System for Critical Infrastructure System Resilience (CISR)

Critical Infrastructure Management System

- Functional Subsystem – Asset Management
- Financial Subsystem
- Decision Making Subsystem
  - CISR Decision-Making Organizations
  - CISR Decisions

Resilience Management Information System

- Decision Support Information (Knowledge Base)
- Time Frame and Post-Disaster Phase (Data)

SDSS
GIS Software (e.g. ArcInfo)

Critical Infrastructure

Physical Subsystem

Administration Subsystem

Geographic Dimension

Disaster Type, Characteristics/Data and Trends

Analysis Tools/Extensions

CISR Decision Support System

- Decision Problems – requirements & constraints
- Insight for Resilience-Based Decision Making

Result Presentation System
GIS ANALYSES FOR CIR-DSS

Study Area

Elevation

Rain Fall
06/25/2010

Vulnerability:
exposure
loss/damage
GIS ANALYSES FOR CIR-DSS

Location of Damaged Infrastructure in the Seaford Flooded Area

Seaford Road Network and Detours Analysis (2006)
HAZUS-MH ANALYSES FOR CIR-DSS

Organizing principle

<table>
<thead>
<tr>
<th>Potential Hazard</th>
<th>Hazard of Interest</th>
<th>Description</th>
<th>Source of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverine Flood</td>
<td>Riverine Flood</td>
<td>On 6/25/06 there was flood (100-year) due to a huge amount of rainfall (12 inches in some areas) which caused serious damage and destruction to roads and bridges infrastructure (49 road network points in Sussex County), the 49 identified points consisted on: 28 roads (segments) with high water, 6 road closures, 2 washed out bridges, 12 road failures, 1 sink hole. Later inspections showed 9 bridges with main problems (i.e. replace structures, flow in fill to restore stream bed under the bridge). Bridges minor problems: repairs of erosion embankments, fill and riprap replacement. It flooded to an elevation of 30 feet high. State of Emergency declared at 2:30 PM – 6/25/2006. Seaford is located at 38°38’41” N, 75°36’58” W (38.644654, -75.616107).</td>
<td>DelDOT – TMC and other Sectors, DEOS, DataMIL, SpatLab</td>
</tr>
</tbody>
</table>

HAZARD: Flood – Seaford, DE

Summary of Risk Factors

<table>
<thead>
<tr>
<th>Rank of factors for local profile</th>
<th>Period of occurrence: June 25, 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity score: high</td>
<td>Probability of event: 1% (100-year flood)</td>
</tr>
<tr>
<td>History: (similar events): 40</td>
<td>Warning time: 1 to 2 days very certain, 10 days trends.</td>
</tr>
<tr>
<td>Vulnerability, (Guessing): 75</td>
<td>Major contributor(s): Low elevation, East coast State, Major river</td>
</tr>
<tr>
<td>Maximum Threat: 80</td>
<td>Risk of injury? Yes, and risk of death</td>
</tr>
<tr>
<td>Probability: 80</td>
<td>Potential for facilities shutdown? Yes. Major roads for 30 days or more</td>
</tr>
<tr>
<td>Total score: 275</td>
<td>Percent of affected properties that may be destroyed or suffer major damage; guessing 15% of local road network</td>
</tr>
</tbody>
</table>

FLOOD (HAZARD) PROFILE (DATA)

Background and Local Conditions

Delaware has moderate risk for snowfall, has more than just a few but not frequent risk for thunderstorms, has moderate to low risk for wind, and some risk for hurricanes. The overall composite risk is moderate. Sussex County in Delaware stands together the other U.S. areas with the most number of disaster declarations given. Seaford, in particular, is located at 38°38’41” N, 75°36’58” W (38.644654, -75.616107), Southwest of Delaware. This area has low elevation, prone to flooding. Seaford’s weather has a mild subtropical climate consisting of hot, humid summers and mild winters, moderated by the Atlantic Ocean. Common to have flooding event occurring also in the Maryland neighboring area, having to share solutions for traffic. Local transportation infrastructure usually in good and fair condition, propitiating the traffic Level of Service A to C. Area prone to be heavily impacted as the ice on the poles melts because of Climate Change - Global Warming.

Historic Frequency and Probability of Occurrence

Floodings is the most common disaster type in the U.S. and for Sussex County. Considering similar events since the 1960’s registered as a Federal Disaster Declaration, the number of events is 4. Earlier events lack easy source for getting the information. Table 5 shows the events and their related damages. Figure 5 shows the related graph considering the time trend among Federal Disaster Declarations (p.s other different and minor events took place in other years).

Severity

Considering other the U.S. areas, Delaware is considered a moderate risk area. However, Sussex in Delaware is the area that most suffers disasters, which matches with other areas that received about the same amount of Federal Disaster Declarations (USGS). In this sense the risk for Flooding can be considered high. According to the flooded area map developed in ArcGIS and studies about global warming, events like the 100-year storm and other more rare events (i.e. 500-year storm) can increase in frequency and strength.

Similar Federal Disasters

Sussex-DE

Historic Losses and Impacts

Great damage has occurred to transportation infrastructure, crops, buildings, and some loss of lives (NOAA). The 2006 flood impacts list for Seaford area includes:

- Damage to the police department situated in the city of Seaford, and the Seaford School District parking lot,
- Barriers and high water signs emergency repairs and placement in the Town of Georgetown, totaling $1,905,
- Traffic control and other security measures of the Delaware State Police, totaling $9,822,
- Road and bridge repair under the responsibility of the Delaware Department of Transportation, totaling $341,888, and
- Road repair work at the Delaware Technical and Community College, totaling $13,340.

Designated Hazard Areas

The elevation profile map and the flooded area map developed earlier using ArcInfo show the areas most prone to flooding. They were built prior to the base map developed in HAZUS-MH. The use of HAZUS-MH software is to do a deeper analysis of the problem.
HAZUS-MH ANALYSES FOR CIR-DSS

Analytical capability

“What if” Levee Protection Scenario

“What if” Flow Regulation Scenario

Floodwater Velocity Estimation Scenario

Damage related to US13 in Sussex County
Study Region: Seaford Case Study
Description: In June 25, 2006 Delaware had a Federal Disaster Declaration
Scenario: Annual_Losses
SDSS BENEFITS AND LIMITATIONS

**BENEFITS**

**PROBLEM DIAGNOSIS:**
GIS + HAZUS-MH

**REPLICATION OF FIELD ACTIVITIES**
E.g. detours

**HAZUS-MH MITIGATION ALTERNATIVES WITH COSTS**
warning system, levee, policy, “what if scenarios” (e.g. river reaches and water speed), flooded area

**LIMITATIONS (HAZUS-MH)**

**ANALYSIS FOCUSES ON LIMITED AREA**

**LIMITED TOOLS TO ANALYZE TRANSPORTATION INFRASTRUCTURE (T.I.)**
Road segmentation not official
Vehicle exposure does not consider flow, just Census
Exposure same as vulnerability?
No dynamic modeling – T.I. resilience changes
No financial trade-off tools for solutions evaluation
WHAT HAVE WE LEARNED?

- Many rich data sources to support decision making
- **Tools**

  **HAZUS-MH MR3**
  - Useful
  - Limited
  - Non-trivial
  - Complementary

  **GIS**
  - Helps communication
  - Provides insight

Analyses results/data integration with Management Information System

- transportation inventory (roads – segments values)
- transportation exposure/vulnerability value
- warning system value (10%)
- connectivity mitigation insight
## HAZUS-MH INVENTORY

Highway Table:

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Owner</th>
<th>SegmentClass</th>
<th>Description</th>
<th>Length</th>
<th>Traffic</th>
<th>Cost</th>
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<tbody>
<tr>
<td>DE000043</td>
<td>Front St</td>
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<td>Default Road</td>
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<td>1.31</td>
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<td>DE000389</td>
<td>Old Bridgeville Hwy</td>
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<td>Default Road</td>
<td>1.99</td>
<td>0</td>
<td>$11,852.4</td>
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</table>
## Transportation System Dollar Exposure

**October 27, 2008**

*All values are in thousands of dollars*

<table>
<thead>
<tr>
<th></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>
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<td><strong>Delaware</strong></td>
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<td>Segments</td>
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<td>0.00</td>
<td>0.00</td>
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<td>Bridges</td>
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<td>0.00</td>
<td>0.00</td>
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<td>Tunnels</td>
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<tr>
<td>Facilities</td>
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<td>0.00</td>
<td>1,188.10</td>
<td>0.00</td>
<td>0.00</td>
<td>5,940.50</td>
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<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>
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<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>
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<tr>
<td><strong>Study Region 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>
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<td>Mitigation Activities</td>
<td>Output</td>
<td>Completed Items</td>
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<td></td>
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</tr>
</tbody>
</table>
| Preliminary options   | Regulatory measures:  
  - reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths)  
  - incentives for mitigation measures implementation, flow regulation  
  - education measures (public awareness)  
  - natural resource protection measure (preserve and restore natural systems)  
Rehabilitation measures (cost, importance, vulnerability?):  
  - structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders)  
  - improve highways lights and signs  
  - remove, relocate, and/or to elevate roads/road segments to meet new performance objectives  
Protective and control measures  
  - floodwalls, levee, warning system (i.e., based on weather forecast)  
  - protective vegetation belts  
  - review and build connections | HAZUS-MH mitigation insights ✓ |
| Review of options     | Regulatory measures:  
  - reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths)  
Rehabilitation measures (cost, importance, vulnerability?):  
  - structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders),  
  - improve highways lights and signs  
  - remove, relocate, and/or to elevate roads/road segments to meet new performance objectives  
Protective and control measures  
  - floodwalls, warning system (i.e., based on weather forecast)  
  - review and build connections | STAPLEE ✓ |
| Final list of options | “Impossible with current HAZUS-MH functions, for exception for the adoption of warning system already included in current results.”  
Although the listed mitigation options could all be analyzed for US13, these options are later carefully reviewed to reach an improved resilience of transportation system goal. HAZUS-MH does not discuss resilience. | To be further explored in STELLA |
| Verification of options | No conflicting measures to mitigate hazard impact. | ✓ |
## CRITERIA FOR EVALUATING MITIGATION MEASURES

<table>
<thead>
<tr>
<th>STAPLEE Criteria</th>
<th>S Social</th>
<th>T Technical</th>
<th>A Administrative</th>
<th>P Political</th>
<th>L Legal</th>
<th>E Economic</th>
<th>E Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Considerations</td>
<td>Community Acceptance</td>
<td>Effect on Population Segment</td>
<td>Technical Feasibility</td>
<td>Long-term Solution</td>
<td>Secondary Impacts</td>
<td>Staffing</td>
<td>Funding Allocated</td>
</tr>
</tbody>
</table>

**Comments:**

Source: (Rock Island County 2008)
INTEGRATING HAZUS-MH DATA

Building the Model - beginning

+ Variables not used in GIS or HAZUS-MH for resilience, functional and financial analysis
  × infrastructure system inventory, condition and performance measures, decision makers and decisions
MAIN ASSESSMENTS

Damage* and Vulnerability Assessments

Impact/Risk Assessment

Resilience Assessment

Decision makers/ Decisions (construction projects)

- Policies recovery/ mitigation
- More resilient system or not

US$ 1 million threshold policy

Depends on Infrastructure overall performance

Note: 1 element in HAZUS risk assess.
<table>
<thead>
<tr>
<th>Steps</th>
<th>Description</th>
<th>Diagram Color and Information Flow Arrow</th>
<th>Case Study Components (Examples)</th>
</tr>
</thead>
</table>
| 1     | a) Choose a CIS  
b) Choose Place and Event  
c) Identify Decision Organizations | | Roads and Bridges; Seafood-DE, Hazard-flood; DEMA, DelDOT |
| 2     | a) Problem Diagnosis  
b) (HAZUS-MH)  
c) Initial mitigation insights focusing in system resilience | | Infrastructure condition before event and hazard; infrast. cond. after event (with/without mitigation); HAZUS assessm.: vulnerability, impact, damage |
| 3     | Pre/post-event comparison | | Performance, Administrative Structure, LCC |
| 4     | Financial | | Resources required to support normal operations |
| 5     | Impact and Resource | | Impact plus resource assessment needed to recover and mitigate damaged CTI |
| 6     | Identify Institutional Constraints – decision makers and factors to restore CIS | | Other constraints – consider CTIS and enhanced system (resilience) |
| 7     | Evaluation, review, and adjustment of analysis (making more resilient systems) | | Evaluate/iterate analysis (inputs required by decision makers – step number six) |
| 8     | Evaluation/communication of results | | Report result – benefits, effectiveness, consequence, methodology, complementary data, options considered, alterations, strategy options (improve CTIS resilience) |
DATA ADJUSTMENTS

• US13 - 4 lanes x 1,900 passenger cars per lane per hour = 7,600

• Carrying/service capacity classification - good (5,070 - 7,600), fair (2,530 – 5,070), poor (1 – 2,530), or none (0)

• “Pavement Condition Index” (PCI) - good prior the disaster = 0.7 (scale 0 to 100)

• Length decimal degrees converted to feet (used projection tool in GIS)
ASSUMPTIONS AND APPROACHES

- Transportation mitigation projects: 100% effective (FEMA specifies 80%)
- Frequency of similar events – which/when recovery or mitigation strategies should be adopted
- “Functional Downtime” for roads/bridges closures determine direct economic impacts
  - Number of days for repair and reopening for traffic
  - Average delay/ detour time for motorist (loss of time)
  - FEMA’s standard value for loss of time = US$32.23
    - benefits of projects in terms of avoided delay
- Hazard mitigation projects for roads/bridges include average daily vehicle count.
Projects BCR determine project effectiveness (requested format from FEMA)

<table>
<thead>
<tr>
<th>Categories of Damages/Benefits</th>
<th>Notes for Mitigation Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Physical Damages</td>
<td>Consider vulnerability according to flooding.</td>
</tr>
<tr>
<td>2a. Loss-of-Function Impacts (e.g. displacement costs)</td>
<td>Not applicable (road and bridge cannot be displaced to temporary other locations).</td>
</tr>
<tr>
<td>2b. Loss-of-Function Impacts Other (e.g. loss of service - economic impact)</td>
<td>Road/bridge closures - generally the largest category of benefits.</td>
</tr>
<tr>
<td>3. Casualties</td>
<td>Generally not significant for flood</td>
</tr>
<tr>
<td>4. Emergency Management Costs</td>
<td>“Generally not considered; road/bridge mitigation projects neglects impact on a communities overall emergency management costs.”</td>
</tr>
</tbody>
</table>
EXAMPLES OF HAZUS DATA IN MODEL
<table>
<thead>
<tr>
<th>Segments</th>
<th>Damaged lanes</th>
<th>Road Issue</th>
<th>Mitigation Strategy</th>
<th>Mitigation Cost (assumption)</th>
<th>Recovery Cost ($)</th>
<th>Associated % per damaged segment value</th>
<th>Related disaster value (thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>de060</td>
<td>2</td>
<td>Road failure</td>
<td>Reinforce (+ resistance)</td>
<td>Recovery cost + 20% 89,242</td>
<td>74,360</td>
<td>57.15</td>
<td>67,604.59</td>
</tr>
<tr>
<td>de066</td>
<td>0</td>
<td>None</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>de068</td>
<td>0</td>
<td>None</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>de069</td>
<td>2</td>
<td>High water</td>
<td>Elevate</td>
<td>Recovery cost + 50% 3,419</td>
<td>2,280</td>
<td>1.75</td>
<td>2,070.13</td>
</tr>
<tr>
<td>de085</td>
<td>1</td>
<td>Sink hole</td>
<td>Reinforce (+ resistance)</td>
<td>Recovery cost + 20% 59,671</td>
<td>49,725</td>
<td>38.22</td>
<td>45,211.68</td>
</tr>
<tr>
<td>de509</td>
<td>0</td>
<td>None</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>de511</td>
<td>1</td>
<td>Road closed</td>
<td>Build containing wall with drainage ducts</td>
<td>Recovery cost + 30% 4,874</td>
<td>3,749</td>
<td>2.88</td>
<td>3,406.85</td>
</tr>
<tr>
<td>Total</td>
<td>--------</td>
<td>----------------</td>
<td>--------------------------</td>
<td>~157,206</td>
<td>~130,123</td>
<td>100</td>
<td>118,293.25</td>
</tr>
</tbody>
</table>
### Table 58 Summary of Benefits for Mitigation Projects

<table>
<thead>
<tr>
<th>Description</th>
<th>Net Present Value of Future Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>No damage to mitigated infrastructure (assuming small part of road segment mitigation is possible instead of the whole segment length)</td>
<td>$118,293.25</td>
</tr>
<tr>
<td>No <strong>Loss of Function</strong> - services value not being provided due to damage (total disaster delay cost)</td>
<td>$601,006.00</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>$719,299.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mitigation Project Costs</th>
<th>$157,206</th>
</tr>
</thead>
</table>

| Benefit-Cost Ratio (Net Present Value of Future Benefits ÷ Project Costs) | 4.6 |

### Table 60 Summary of Benefits for Recovery Projects

<table>
<thead>
<tr>
<th>Description</th>
<th>Net Present Value of Future Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible repetition of damage to mitigated infrastructure (no certainty of extent of damage possible to be bigger and/or smaller, despite physical conditions improvement)</td>
<td>($118,293.25)</td>
</tr>
<tr>
<td>Possible repetition of <strong>Loss of Function</strong> - services value not being provided due to damage (total disaster delay cost)</td>
<td>($601,006.00)</td>
</tr>
<tr>
<td>Improved road condition (1% - average IS recovered condition)</td>
<td>$1% \times (118,293.25 + 601,006.00) \rightarrow ($23,042.00)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
</tr>
<tr>
<td>Recovery Project Costs (total lanes recovery cost)</td>
<td>$130,123.00</td>
</tr>
</tbody>
</table>

| Benefit-Cost Ratio (Net Present Value of Future Benefits ÷ Project Costs) | -0.18 |

35
Scenarios Explored

Eight scenarios assessing impacts (costs) uses:

- Infrastructure Projects
  - Recovery only
  - Recovery and Mitigation

- Probability of a 100-year storm event in the case study area
  - 1%
  - 4%
  - 8%

- Time required for disaster response
  - 2 days
  - 4 days
ILLUSTRATIVE RESULTS

- 1% probability of 100-year storm (study area)

<table>
<thead>
<tr>
<th>Variables</th>
<th>2 days Disaster Response</th>
<th>4 days Disaster Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery NPV</td>
<td>148,081</td>
<td>512,958</td>
</tr>
<tr>
<td>Mitigation NPV</td>
<td>157,890</td>
<td>600,629</td>
</tr>
<tr>
<td>Result from mitigation investment</td>
<td>-9,809</td>
<td>-87,671</td>
</tr>
<tr>
<td>Loss of function for recovery (benefit)</td>
<td>-1,463</td>
<td>-2,479</td>
</tr>
<tr>
<td>Loss of function for mitigation (benefit)</td>
<td>719,299</td>
<td>1,218,060</td>
</tr>
</tbody>
</table>
CONCLUSION

• Complex system modeling required many assumptions and models to capture changes over time

• SDSS plays major role in setting the stage for problem analysis, diagnosis, mitigation insights (many sources of data)
  • SDSS results are important inputs into the model
  • SDSS can be better customized to include better analysis tools for infrastructure
  • HAZUS-MH inventory enables further analyses, integration and shows the potential to add/improve analyses for infrastructure

• Comprehensive development offers insights into trade-offs and opportunities to capture damage and costs in the context of resiliency

• Refinements are needed
FUTURE WORK WITH HAZUS AND EXPECTED BENEFITS

- Include FEMA BCA tool kit in HAZUS-MH expand insights of mitigation strategies and projects towards making HAZUS better help support decision making.
- Level 2 analysis customizing transportation infrastructure inventory and include calculation of roads/bridges debris in the cost for recovery and mitigation.
ACKNOWLEDGEMENTS

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