ESTIMATING THE EFFECTS OF EXTREME WEATHER ON TRANSPORTATION INFRASTRUCTURE
PROJECT UPDATE – JULY 11, 2013

Mark Abkowitz & Janey Camp – Vanderbilt University
Tracey Holloway & Monica Harkey – University of Wisconsin - Madison
The Outlook

• Irrespective of whether our climate is changing, today’s extreme weather events will cause greater risk in the future due to evolving land use, demographics and resource consumption.

• The extent to which extreme weather may induce more frequent and severe weather will only exacerbate what is already a grave situation.

• Much of our existing infrastructure is nearing the end of its useful life and was built using design guidelines that are no longer valid.
The Problem

• Extreme weather events will challenge the vulnerability and resilience of the freight transportation infrastructure to serve society’s needs.

• Current damage assessment models do not adequately take freight transportation impacts into consideration.

• Consequently, potential disruptions to freight mobility in the coming decades are not well characterized.

• Understanding future extreme weather scenarios and having accurate damage assessment models are a necessary part of identifying cost-effective adaptation strategies.
Research Objectives

• Develop and pilot test a methodology that can identify highway infrastructure that is most threatened by flooding events.
• Define the correlation between flooding and road closures as an initial component of a transportation and extreme weather risk index.
• Estimate the actual damage due to flooding to the highway infrastructure itself and related indirect effects (e.g., delays in shipments, increased travel times and fuel costs).
• Provide a means for: 1) evaluating the potential impacts of extreme weather on highway infrastructure systems due to flooding and 2) determining the benefits of candidate adaptation strategies.
• Provide a basis for transferability of the research results to:
  • flood risk associated with other freight modes
  • risks of other extreme weather events impacting freight transportation infrastructure and operations
Work Plan

• Develop flood risk index to describe extreme precipitation events based on historic rainfall, soil properties, etc.
• Correlate observed flooding events that caused highway freight disruption with extreme weather predictions and risk index.
• Select two sites that experienced a recent flooding event for which highway infrastructure damage was significant.
• Compare damage assessment model predictions with observed impacts at each site.
• Enhance damage assessment model, as appropriate, so that it is representative of the full impacts of flooding events on highway freight transportation infrastructure and operations.
• Develop future flooding scenarios using extreme weather forecasts and the risk index; apply enhanced model to estimate highway freight transportation impacts.
Accomplishments to Date

• Began collection and evaluation of data on significant historic road closings and other metrics of transportation disruption.

• Began an evaluation of the impacts associated with the May 2010 flood event that occurred in the Nashville, TN area. This included damage assessment modeling using Hazus, review of information collected by local agencies, and design of a household survey of impacted residents.

• Developed preliminary flood risk index based on road and precipitation conditions.

• Plotted severity of extreme precipitation events: data from the North American Regional Reanalysis (NARR) were mapped over the Southeastern U.S. to show frequency of precipitation above varying thresholds.

• Compared NARR historic precipitation data to local observations of precipitation amounts in Tennessee. In order to gauge model simulations of extreme precipitation, average daily maximums of NARR precipitation were also compared to precipitation from the North American Regional Climate Change Assessment Program (NARCCAP) archive of historic climate simulations, focusing on Nashville, TN.
2010 NASHVILLE FLOOD – HAZUS MODEL EVALUATION
2010 Nashville Flood – Overall Impacts

- 11 fatalities and an estimated $2 billion in damages to private property
- Historic buildings damaged
- Economic centers shut down
- Thousands of claims filed with FEMA
- Many of those affected (46%) located outside of the 100-year floodplain and did not have flood insurance
- Months of cleanup - Tons of debris and waste (some toxic)
Transportation System Impacts

- Roadways and rail lines severely damaged and destroyed
  - Alternate (possibly longer) routes had to be used
  - Increased fuel and transport costs
- Equipment fleet and cargo loss
- Waterway navigation slowed or halted for days until flood waters receded
- Repairs for some infrastructure took several months or more
- Suppliers and customers looked for alternate modes
Hazus Damage Assessment Model

- A tool to help communities and managers assess potential damages of natural hazard events
- Developed by the U.S. Federal Emergency Management Agency (FEMA) to address flood, hurricane and earthquake damage estimation
- Performs two-dimensional estimation of flood extent and depth
- Contains U.S. Census data for housing, population and economic factors for consideration in damage cost estimation
- Utilizes spatial information as an extension to ESRI’s ArcGIS software
Sample Hazus Output
(USACE HEC-RAS MODEL CALIBRATED TO 2010 FLOOD DEPTHS USED IN HAZUS)

Estimated number of buildings requiring complete replacement per census block.
Hazus Damage Cost Estimates

- Using USACE HEC-RAS Output
  (Calibrated to 2010 Flood)
  - Building loss = $2.7 billion
  - Business interruption = $14 million
  - Transportation system (bridges only) = $5.1 billion
  - Utilities = $1.4 billion
  - Agriculture = $20.1 million
  - TOTAL = ~$9.2 billion

- Using Hazus 1000-yr Storm
  - Building loss = $2.24 billion
  - Business interruption = $14 million
  - Transportation system (bridges only) = $5 billion
  - Utilities = $1.4 billion
  - Agriculture = $20 million
  - TOTAL = ~$8.64 billion

Cost Comparison
Metro Planning Office Estimate = $2 billion in direct property damages
Identifying Unaccounted for Direct and Indirect Costs – Household and Business Surveys

- Targeted specific areas of Davidson County with range of exposure and income levels to conduct surveys of households and businesses

<table>
<thead>
<tr>
<th>Low Income</th>
<th>Moderate Income</th>
<th>High Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Damage</td>
<td>Low Damage</td>
<td>Low Damage</td>
</tr>
<tr>
<td>Moderate Damage</td>
<td>Moderate Damage</td>
<td>Moderate Damage</td>
</tr>
<tr>
<td>High Damage</td>
<td>High Damage</td>
<td>High Damage</td>
</tr>
</tbody>
</table>

- Damage levels obtained from initial HAZUS run (1000-yr economic losses)
- Used GIS to select locations and identify target parcels

- Household survey mailouts occurred in three phases
  - Response rate ~ 25%
- Business survey – currently under analysis
Household and Business Survey Results

- Of those households surveyed....
  - 26% had no damages
  - 23% had minimal damage
  - 18% had moderate damage
  - 25% had severe damages
  - Only 19% had flood insurance
  - 48% had to relocate for at least a short period of time
  - 6.5% suffered some type of injury from the flood and spent an average of $280 on medical expenses
  - Another 7% had chronic health problems resulting from the flood
  - Average household repair and recovery costs (insurance, FEMA, SBA loans, etc.) = $23,800
  - Average relocation costs = $1,101
  - Average time for recovery = 63 days
  - Average equivalent cost for volunteer labor contributions = $19,302

Of those businesses surveyed....
- Average business repair and recovery costs = $465,000
- At least some impacts to obtaining materials and supplies
- A significant impact to shipping out products
- For those significantly impacted, the inability to ship and receive goods lasted at least one month
- Only a few had flood insurance, but most had business continuity insurance

Hazus estimates for all zones considered:
- 7% will require sheltering
- 1.5% will have minimal damage
- 25% will have moderate damage
- 73% will have severe damage
- Average repair/replacement costs = $37K
Hazus and Survey Evaluation Summary

- Based upon survey results Hazus...
  - Overestimates the building loss (replacement and recovery costs)
    - The built-in survey data was from 2000, not 2010
    - The housing market crash should be considered in comparisons
  - Underestimates the number of persons displaced
  - Does not account for recovery time
  - Does not account for in-kind labor donations
  - Requires user-modified inputs to improve approximations
    - Census and property value data must be up to date for representative results
    - Averages are for entire census blocks as opposed to just the inundation areas causing skewing if only a small portion of the census block is inundated
    - Indirect costs such as volunteer labor, health impacts, etc. should also be considered
  - Does not account for transportation system delays and disruptions or losses to infrastructure beyond bridges
One Source of Potential Hazus Errors

Areas:

Over predicted = 16.49 sq mi

Under predicted = 19.35 sq mi

HAZUS 1000-yr flood event estimation compared to 2010 flood inundation area.
CORRELATING KEY PRECIPITATION EVENTS WITH TRANSPORTATION INFRASTRUCTURE DAMAGE IN TENNESSEE
95th Percentile Daily Precipitation Events for Tennessee Between 1995 and 2010

Each point represents a weather station reading with size indicative of the amount of precipitation and each color represents a single date. All points represent 24-hour totals for precipitation exceeding 5”. May 2010 was excluded from this plot to identify other dates with high precipitation to evaluate.
Precipitation values range from 1.16” to 17.7”
Tennessee Major Road Closures and Cautions due to Flooding (2006-2010)
Correlating Road Closures with High Precipitation
Limitations in Correlating Road Closures with High Precipitation Events

- Causes for non-correlation
  - Road closures caused by flooding due to construction
  - Lack of gauges nearby to identify precipitation amounts
  - Precipitation may be less than 5” threshold used to select gauges
  - High precipitation may not have led to road closures in the area – adequate drainage, etc.

- Overcoming the challenge – consider other metrics
  - Repair and maintenance logs from TDOT and other highway management agencies
  - Traffic flow and detour data
  - News reports and social media
DEVELOPMENT OF A RISK INDEX
Development of a Risk Index

- Risk = frequency*consequences = likelihood * impact

- Candidate risk metrics
  - Probability of precipitation exceeding average design storm for area
  - Amount of freight delayed or detoured
  - Possible extent of damage or user access to infrastructure (embankment or roadbed damage, scouring, under standing water, complete failure)

- Factors to consider:
  - Infrastructure characteristics (e.g., age, condition, stability, slope, elevation, proximity to hydrologic features, availability of alternate routes)
  - Antecedent conditions (soil saturation, preceding weather conditions, etc.)
EVALUATION OF NARR AND NARCCAP TO MODEL EXTREME PRECIPITATION EVENTS
How often does the Nashville International Airport area observe 2+ inches of rain in a day in the warm season (March – October)?

* 40% increase in the frequency of warm-season daily accumulated precipitation >= 2 inches, from 1995-2010 to 2040-2070.
What is the maximum daily accumulated precipitation in the Nashville International Airport area, during the warm season?

The highest daily total precipitation was 3.8 inches in one day—part of the May 2010 event.

May 2010-like events may not only become more frequent, but also more severe, with higher maximum daily precipitation amounts, exceeding 5 and 6 inches in a day.
The area-averaged frequency of precipitation greater than 2 inches in the warm season:
1995-2010: 15 days
2041-2070: 44 days
NEXT STEPS
Next Steps

• Map the probability of precipitation for the Southeastern U.S. and Upper Midwest. These will aid in selection of the second site of interest.

• Select the Upper Midwest site based on the aforementioned information and additional analysis, as appropriate.

• Continue evaluation of transportation infrastructure damage measures to assist in further development of risk index.

• Continue comparison of NARR and historic NARCCAP precipitation, focusing on Nashville, TN, as well as the site in the Upper Midwest.

• Utilize risk index and future climate projection models to identify future vulnerable transportation infrastructure locations.
FUTURE RESEARCH OPPORTUNITIES
Future Research Opportunities

• Demonstrate how the information from this project can be utilized to evaluate the benefits and costs associated with candidate highway infrastructure adaptation strategies
• Expand study to rail and other modes
• Evaluate future extreme weather impacts associated with hurricanes and coastal flooding to multi-modal freight transport using Hazus and NARCCAP models
Thank You!