First JSCE-ASCE Joint Symposium on Infrastructure Resilience

Session 2: Climatological, Hydrological and Geotechnical Risks
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CIVIL & ENVIRONMENTAL ENGINEERING

Motivation

• Examples:
  – Irene – Vermont, August 2011
  – Matthew – North Carolina, October 2016
  – Harvey – Texas, August 2017
  – Maria – Puerto Rico, September 2017
  – Florence – North Carolina, September 2018

Sources:
https://en.wikipedia.org/wiki/Hurricane_Irene
Hurricane Matthew
2016 Oct. 9th, closed all lanes.
Until Oct. 18th, partial closure between Exit 81 and Exit 13.
On Oct. 18th, I-95 reopened.

Hurricane Florence
2018 Sept. 15th, closed all road.
18th to 24th, Lanes heading south closure between Exit 138 and Exit 119.
15th to 16th, Partial closure between Exit 118 and Exit 81.
15th to 24th, Closure between Exit 81 and Exit 13.
23rd (evening), I-95 reopened.

Detours:
• via I-440, US1, I-74
• via I-62, 301 and I-74.
• via I-64 to I-540 West to I-40 West to US321 to I-85. (Only during Hurricane Florence)
Key Questions

- How should the issue of a significant level of uncertainty in prediction be dealt with in planning?
- What kind of flood control management system is necessary to minimize flood damages?
- What kind of legal and social reforms are necessary to implement such a management system?
- What are the basic principles of flood control facility design? How are fatal failures prevented by structural design?
- How are safety and risks of flood control facilities such as levees and dams evaluated?
- What is important in quick recovery and reconstruction in terms of resilience?
- How is society’s resilience against disasters evaluated?
Objective

To model the loss of resilience in the transportation network during recovery following flooding

To explore alternative scenarios
Definitions of resilience

• “...withstand and absorb changes during an environmental disturbance” (Holling, 1973)

• “anticipate, absorb, adapt to, and recover rapidly when hazards occur” (NIAC, 2009)

• “...the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions.” (Presidential Policy Directive 21).

Four attributes of resilience

• Robustness
  – Functionality remaining

• Redundancy
  – Alternatives (routes/modes)

• Rapidity
  – Time taken for recovery

• Resourcefulness
  – Available resources

(Bruneau et al, 2003)
Possible functionality to measure:

1) Total travel time  
2) Travel distance  
3) Connectivity  
4) Number of alternative routes  
5) Capacity  
6) Traffic flow

Methodology

Network  Code Selue  Total Travel Time During Flooding  Alternative Strategies

OD Matrix  Travel Time per Day  Scenarios

travel time  travel distance
Disruptions due to Matthew

- Significant inconvenience for travelers.
  - Total travel time increased from 2.8 m hours to 3.2 m hours.
  - 1.3 m extra miles per day.
  - $5.8 m loss due to flooding.
- The travel time during full closure > during partial closure.
- Partial closure leads to minimal disruption.

Disruptions due to Florence

- Significant inconvenience to travelers.
  - Day 4: Largest additional travel time during flooding, around 1,000,000 hours.
  - Travel times during full closure > during one direction closure > during partial closure.
- Hurricane Matthew Vs Hurricane Florence
  - Significant extra travel times and delay costs incurred by the road users.
  - Travel time during Florence is much larger because larger area is disrupted.
- Partial closure is a relatively effective and efficient strategy if feasible.
Most travel times lower than the base case.

The influence of staying home and using local roads is significant.

Matthew: Alternative Scenarios

Limitations

Feasibility: The repair time involved many factors: access, weather conditions, & resources
Increased cost
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- How is society’s resilience against disasters evaluated?

Conclusions and Recommendations

How should the issue of a significant level of uncertainty in prediction be dealt with in planning?

Mitigation
- Strengthening vulnerable locations
- Prepositioned equipment/materials
- Mutual aid agreements
- Contracts/training/sensors

Preparedness
- Detours/Road closures
- Debris removal
- Temporary repairs

Response

Recovery
- Efficient repair and replacement
- Adaptation
Conclusions and Recommendations

What is important in quick recovery and reconstruction in terms of resilience?

- Extra total travel time is significant
- Cost of extra time and extra miles considerable economic loss
- There are negative impacts on local road, like traffic jams or road deterioration

Partial closure is an effective way to increase resilience

- Compared to normal situation, partial closure is more closer to situation before flooding. The travel time changes due to partial closure < closing
- Up to 40% decrease in travel time.
- Repairing the link with higher annual daily traffic (AADT)
- Shorten repair time is an effective way to reducing total travel time
- Limited by feasibility

The influence of staying home and use of local roads is significant

- Extra travel time and extra vehicle miles of travel

There are two recommendations based on alternative strategies.

Conclusions and Recommendations

How is society’s resilience against disasters evaluated?

- Captures loss of resilience during recovery
- Captures redundancy, rapidity, resourcefulness
- Robustness captured in terms of extent of damage but not amount of damage
- Pre-event versus post event
- Other social impacts (stress, equity, trips lost, disruption to businesses)

Questions?


I-95 covered in water in Lumberton, NC, 2017
• University of Delaware
  – Daniel Liu
  – Tingchi Ren
• Center for Advanced Infrastructure and Transportation (CAIT), Rutgers University
• North Carolina DOT