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First JSCE-ASCE Joint Symposium on Infrastructure Resilience

Session 2: Climatological, Hydrological and Geotechnical Risks

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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
http://wunc.org/post/dam-breached-sixty-miles-i-95-closed-matthews-aftermath
https://qz.com/1063637/texas-floods-these-before-and-after-photos-from-tropical-storm-harvey-show-the-scale-of-houstons-flooding/
http://bigthink.com/connected/heres-what-puerto-rico-looks-like-after-hurricane-maria

Hurricane Matthew and Hurricane Florence

Hurricane Matthew

2016 Oct. 9th. Closed all lanes.
Until Oct 15th, closure between Exit 119 and Exit 13
Until Oct. 18th, partial closure between Exit 81 and Exit 13
On Oct. 18th, I-95 reopened

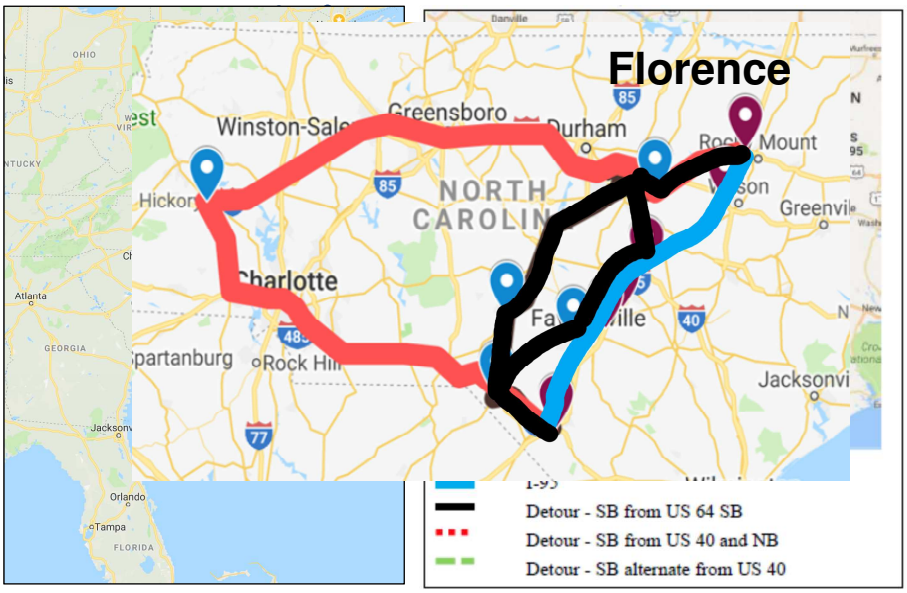
Hurricane Florence

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 I40 West to US321 to I85. (Only during Hurricane Florence)

Hurricane Matthew and Hurricane Florence



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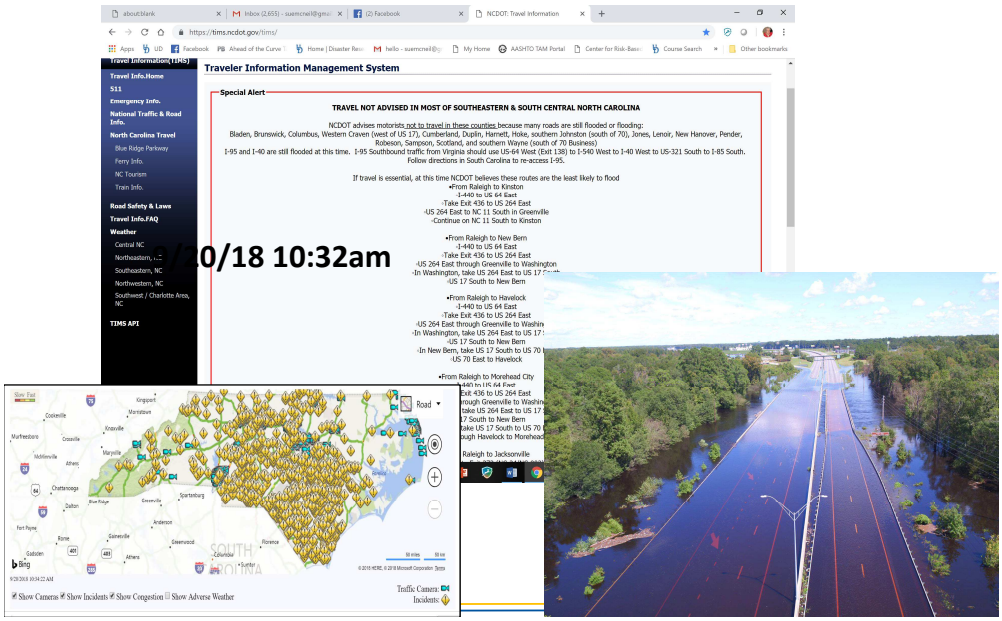
Motivation



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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?

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Outline

- Objective
- Case study
  - Resilience measures
  - Methodology: Loss of resilience due to flooding
  - Alternative scenarios
  - Lessons learned

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Objective

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

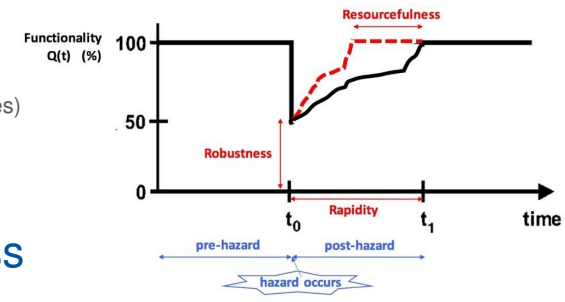
- To explore alternative scenarios

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**).

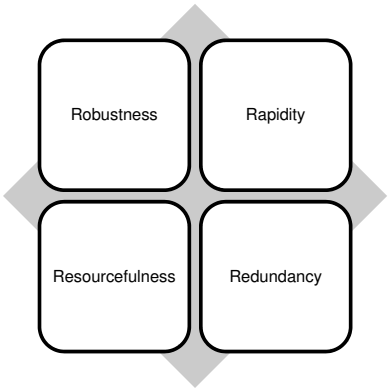
Four attributes of resilience

- Robustness
  - Functionality remaining
- Redundancy
  - Alternatives (routes/ modes)
- Rapidity
  - Time taken for recovery
- Resourcefulness
  - Available resources



(Bruneau et al , 2003)

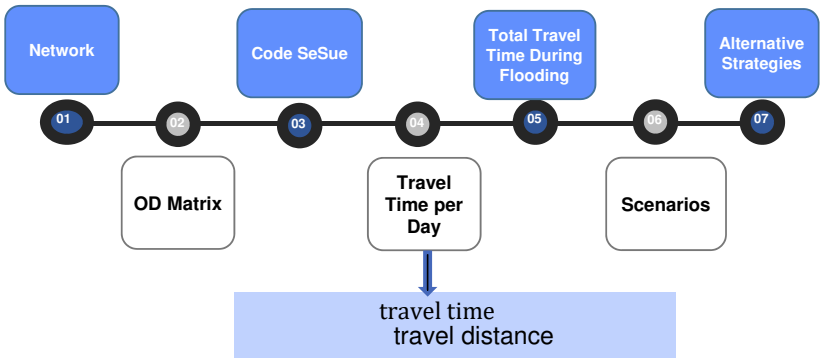
Measure of transportation network resilience



Possible functionality to measure:

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

Methodology



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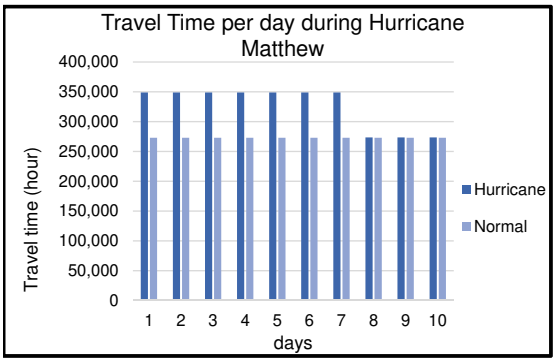
Disruptions due to Matthew



- ❑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

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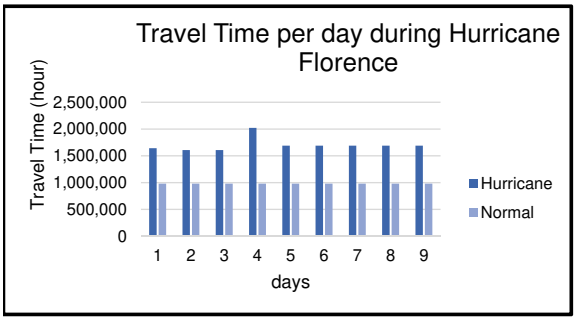
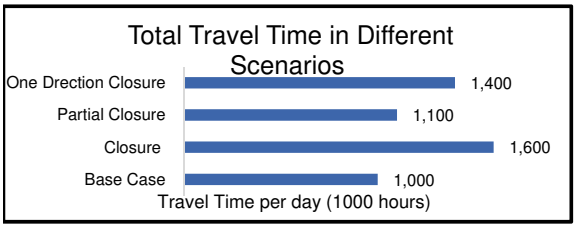
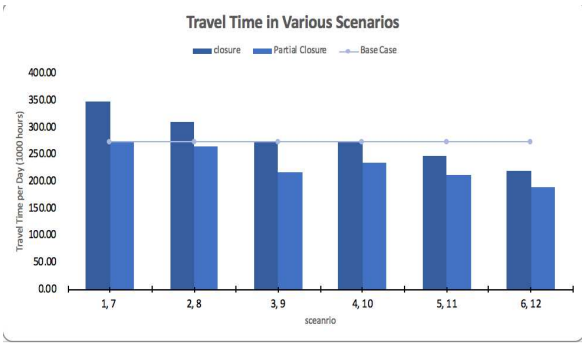
Disruptions due to Florence





- ❑ 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.

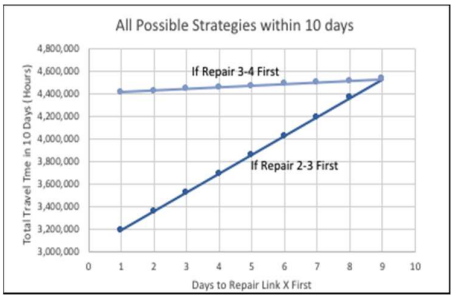
Matthew: Alternative Scenarios

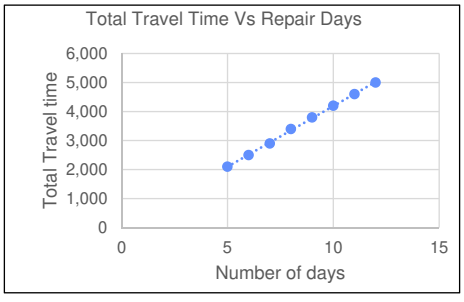


- Most travel times lower than the base case.
- The influence of staying home and using local roads is significant.

1. 2-3 and 3-4 are closed
2. when 2-3 & 3-4 closed, 10% user stay at home while others all use the network.
3. when 2-3 & 3-4 closed, 20% user stat at home while others all use the network.
4. when 2-3 & 3-4 closed, User drive as normal (0% stay at home) while 50% of users use local road instead of the network.
5. when 2-3 & 3-4 closed. 10% user stay at home while 50% of users use local road instead of the network.
6. when 2-3 & 3-4 closed, 20% user stay at home while 50% of users use local road instead of the network.
7. partial closed
8. when partial closed, 10% user stay at home while others all use the network.
9. when partial closed, 20% user stat at home while others all use the network.
10. when partial closed, User drive as normal (0% stay at home) while 50% of users use local road instead of the network.
11. when partial closed. 10% user stay at home while 50% of users use local road instead of the network.
12. when partial closed, 20% user stay at home while 50% of users use local road instead of the network.

Matthew: Alternative Strategies





Repairing the link with higher AADT cause lower extra travel time

Smaller repair time, smaller delay cost;

Limitations

- Feasibility: The repair time involved many factors: access, weather conditions, & resources
- Increased cost

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Conclusions and Recommendations

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

Mitigation	• Strengthening vulnerable locations
Preparedness	• Prepositioned equipment/ materials • Mutual aid agreements • Contracts/ training/ sensors
Response	• Detours/ Road closures • Debris removal • Temporary repairs
Recovery	• Efficient repair and replacement • Adaptation

Conclusions and Recommendations

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

These two case studies show Hurricanes cause serious negative impact on travelers.	• 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
The influence of staying home and use of local roads is significant	• Up to 40% decrease in travel time.
There are two recommendations based on alternative strategies.	• Repairing the link with higher annual daily traffic (AADT) • Shorten repair time is an effective way to reducing total travel time • Limited by feasibility

Conclusions and Recommendations

How is society's resilience against disasters evaluated?

Extra travel time and extra vehicle miles of travel	• Captures loss of resilience during recovery • Captures redundancy, rapidity, resourcefulness • Robustness captured in terms of extent of damage but not amount of damage
Questions?	• Pre-event versus post event • Other social impacts (stress, equity, trips lost, disruption to businesses)

I-95 covered in water in Lumberton, NC, 2017
Source: https://www.bbc.com/news/world-us-canada-37625055

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