UTC Spotlight Conference 2017
Rebuilding and Retrofitting Transportation Infrastructure

Asset Management Track

Asset Management and Resilience: Connecting the Concepts to Building and Rebuilding

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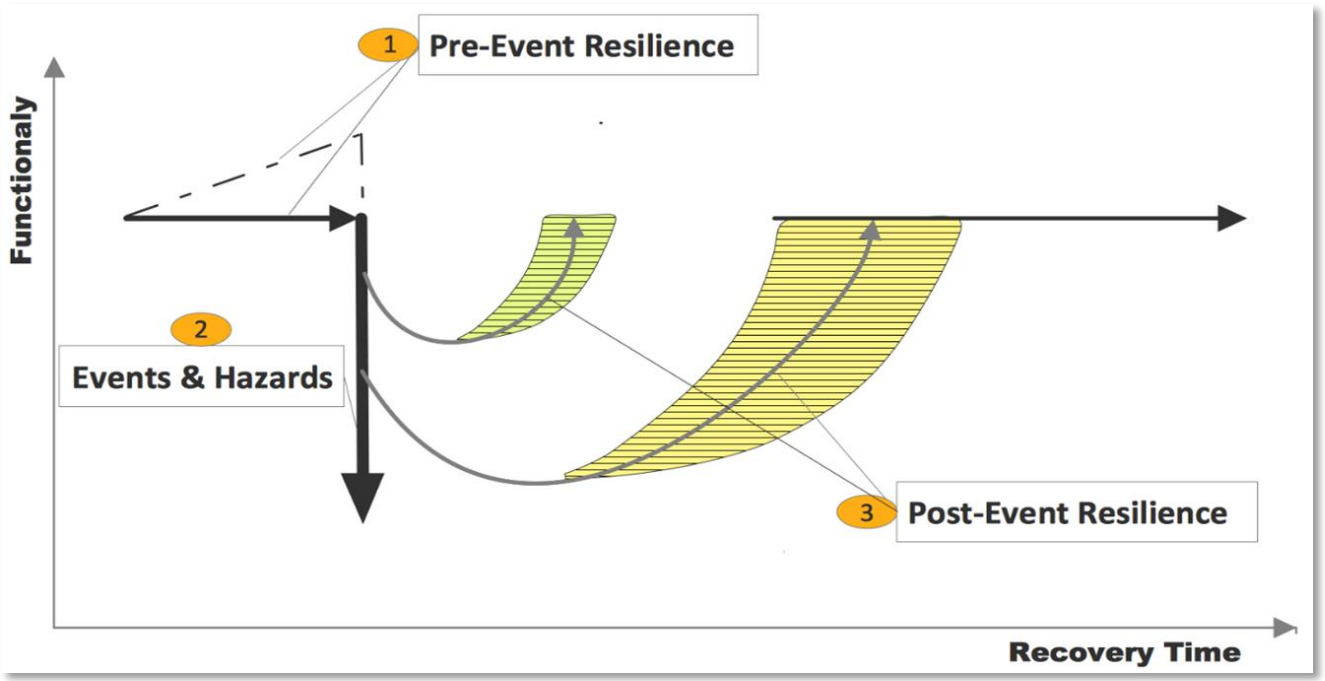
Motivation

- Interest in resilience
- Awareness of climate change impacts
- Occurrence of extreme events
- Legislation
  - Focus in MAP-21 on performance based management and risk-based asset management plans
  - Inclusion of “resilience” in FAST

Why measure infrastructure resilience?

- Mandated for transportation
- Assessment and comparison
- Decision support

Resilience Concept



Adapted from Bruneau et al. 2003, McDaniels et al. 2008, and McAllister 2015

Resilience Principles

- **Resilience**: capability to resume operations as pre-event levels.
- Attributes of resilience
  - Robustness
    - Loss of functionality
  - Rapidity
    - Time to recovery
  - Resourcefulness
    - Rate of recovery
  - Redundancy
    - Network impact

Two perspectives for transportation resilience

- Users:
  - Disruption and inconvenience
- Owners:
  - Damage, repair, and recovery

Possible for transportation resilience

- User's perspective:
  - Travel time
  - Vehicle Mileage traveled (VMT)
  - Disruption duration
- Owner's perspective:
  - Condition, and location
  - Capacity
  - Accessibility

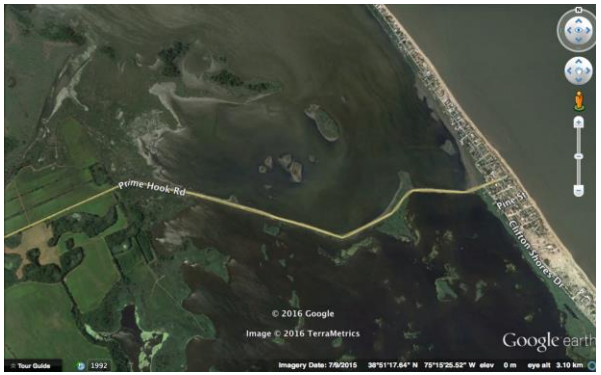
Two levels of analysis

- Project level
- Network level

Case studies

- Project level
  - Primehook Road, Delaware
- Network level
  - I95, North Carolina

Case studies



- Project level
  - Primehook Road, Delaware
  - Remote road with recurrent flooding
- Network level
  - I95, North Carolina
  - Interstate highway damaged by Hurricane Matthew

Project level case study

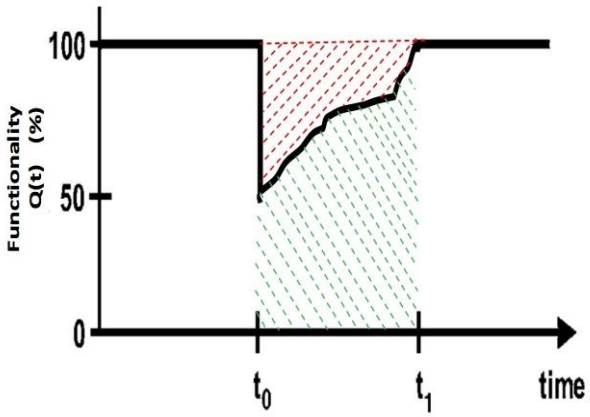
Two measures of resilience

- Bruneau et

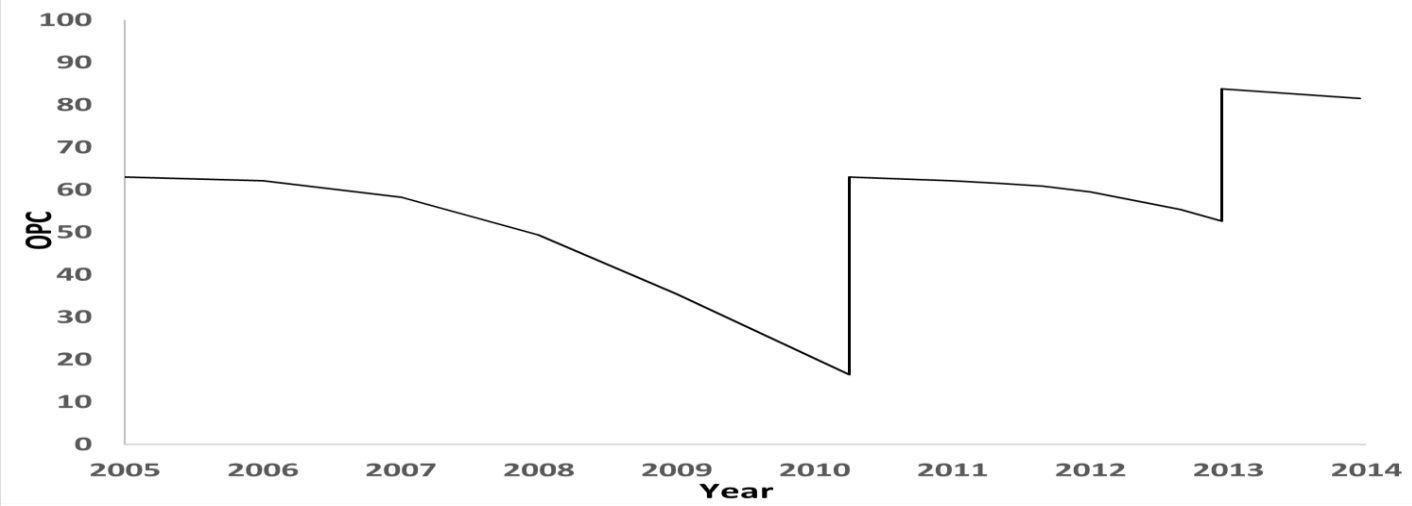
$$R_L = \int_{t_0}^{t_1} \big(1 - Q(t)\big)dt$$

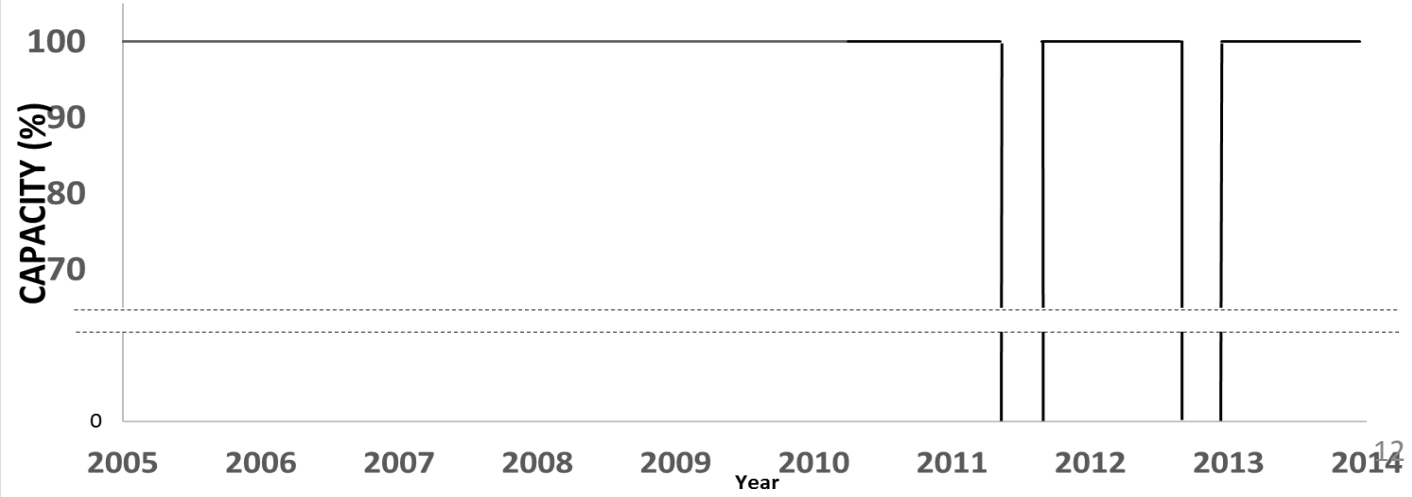
- Bocchini ar[illegible]

$$R = \frac{\int_{t_0}^{t_1} Q(t)dt}{t_1 - t_0}$$



Project level case study





Project level case study

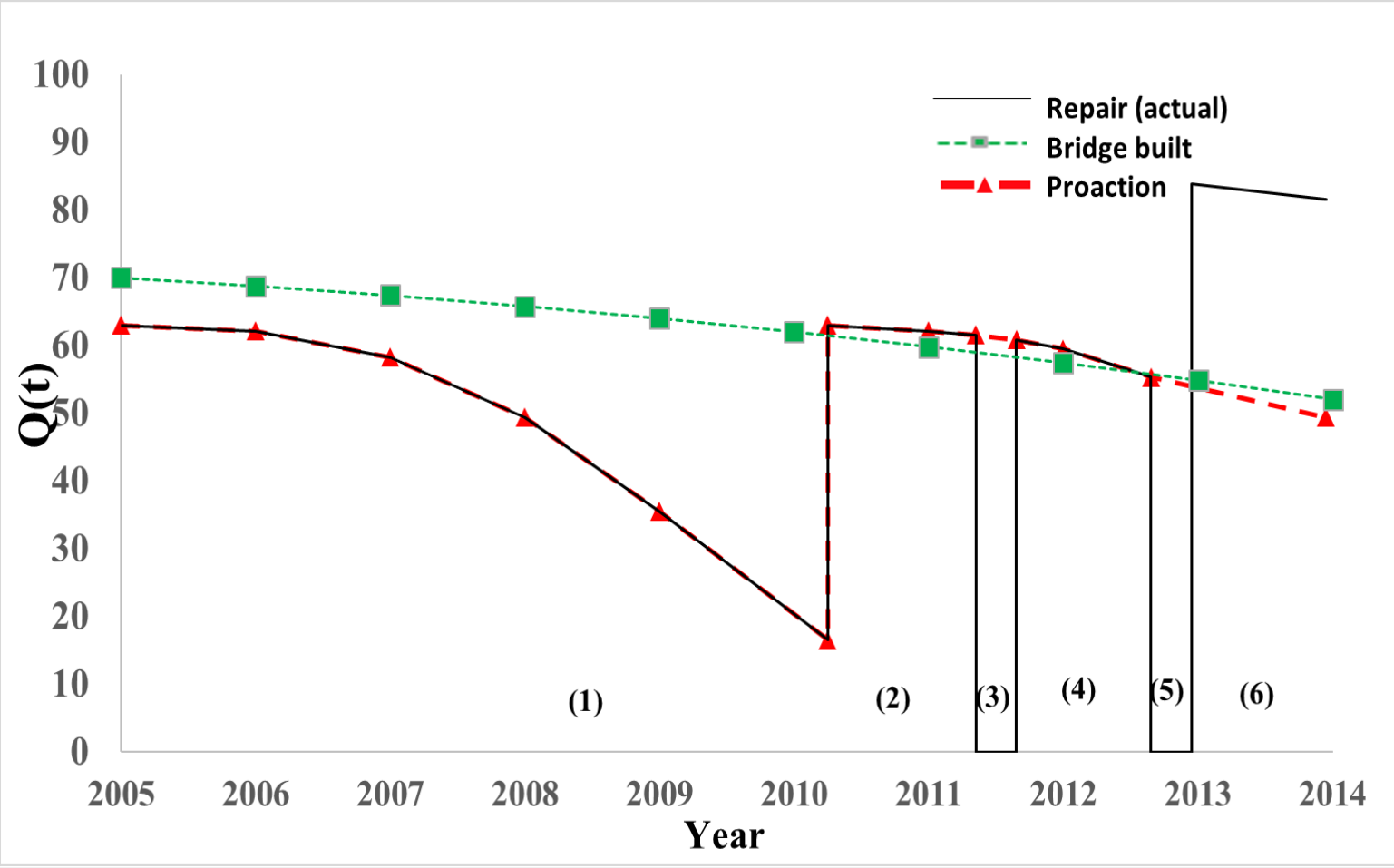
Three scenarios

I. Repair (Actual)

II. Bridge built

III. No closure due to proactive prevention but subbase saturated

Project level case study

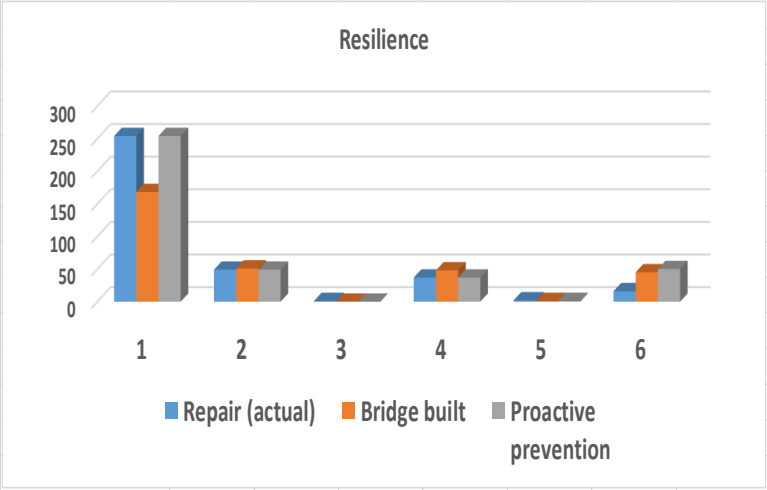


Project level case study

Bruneau et al.

$$R_L = \int_{t_0}^{t_1} (1 - Q(t))dt$$

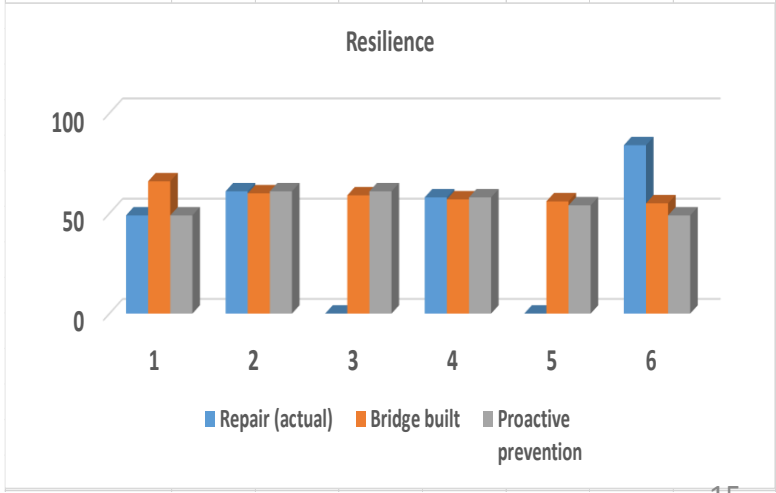
Scenario	Period						
	1	2	3	4	5	6	Overall
Repair (actual)	254	49	1	37	2	16	361
Bridge built	168	51	0	48	1	45	313
Proactive prevention	254	49	0	37	1	50	392



Bocchini et al.

$$R = \frac{\int_{t_0}^{t_1} Q(t)dt}{t_1 - t_0}$$

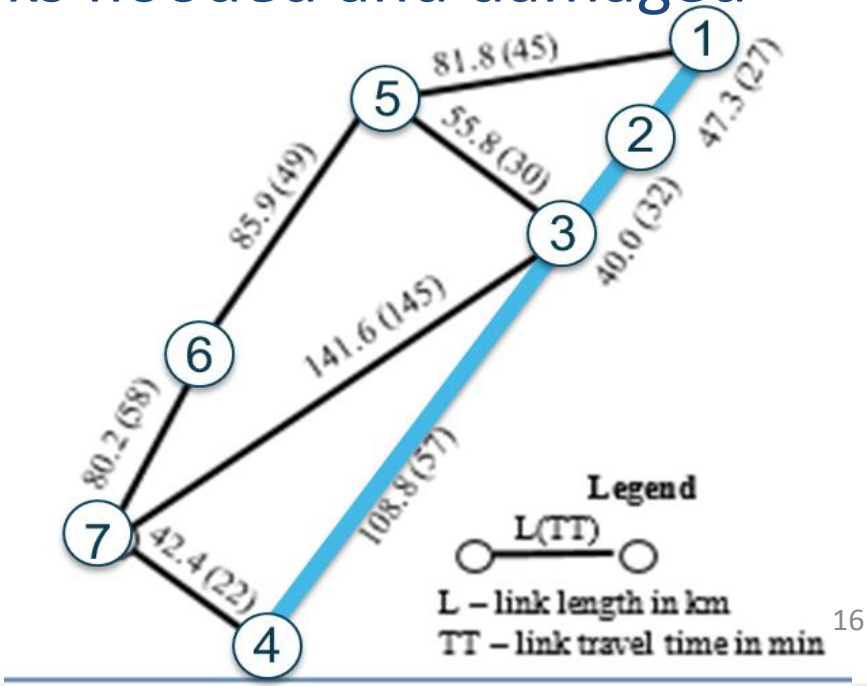
Scenario	Period						
	1	2	3	4	5	6	Average
Repair (actual)	49	61	0	58	0	84	56
Bridge built	66	60	59	57	56	55	63
Proactive prevention	49	61	61	58	54	49	52



Network level case study

Situation:

1. Interstate closure: links flooded and damaged
2. Partially reopened
3. Fully reopened



Measures of resilience

- Additional total travel time
  - $R = \sum_{t=1}^{T} \sum_{i=1}^{n} (TT_{it} q_{it} - TT_{i0} q_{i0})$
- Additional total Vehicle Miles Traveled (VMT)
  - $R = \sum_{t=1}^{T} \sum_{i=1}^{n} (L_i q_{it} - L_{i0} q_{i0})$

Notation: R = Resilience

t = time index (in days), and T = duration of the event

i = link index, and n = number of links

TT_{it} = travel time on link i on day t (minutes),

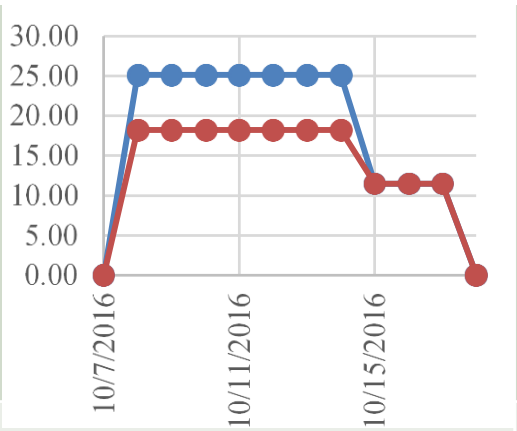
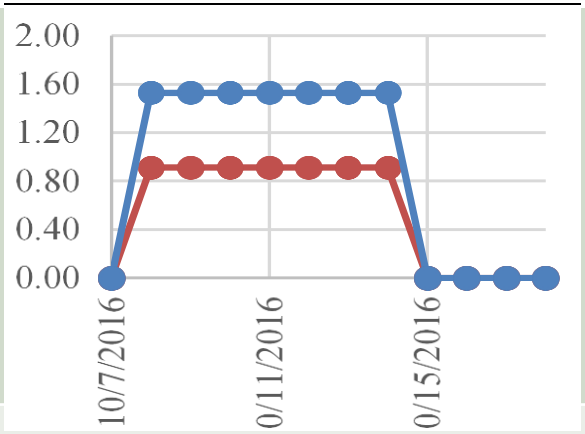
TT_{i0} = travel time on link i before the event (minutes),

q_{it} = flow on link i on day t (vehicles per day),

q_{i0} = flow on link i before the event (vehicles per day)

L_i = length of link i (km)

Results

	Extra Travel time (thousand hour)	Extra VMT (millions kilometers)
10% less travel 20% less travel		
Resilience 10% less travel	210.4	10.7
Resilience 20% less travel	162.2	6.4
Cost ($M) 10% less travel	4.21	3.35
Cost ($M) 20% less travel	3.24	2.00

Observations I95, NC

- Measures reflect users' perspectives
- Recovery process is not reflected in VMT measure
- Cost is easier to interpret

Conclusions

- Retrospective analysis
  - Measurement is possible
  - Many measures available
  - User's and owner's perspectives differ
  - Measures difficult to interpret
- Prospective analysis
  - Challenging

Research Questions

- How do state, regional and local governments operationalize the concept of resilience?
- What measures do they use, how do they interpret the measures, and how do they use the measures of resilience?
- What does resilience mean for life cycle cost?
- Is resilience just another level of service, or performance measure?
- How does resilience recognize the number of users affected by a disruption?
- Is resilience an appropriate metric for an objective function or is resilience part of multi-attribute decision making?
- How does resilience relate to sustainability?
- Is resilience the complement of risk/ vulnerability?

Thank you

Q&A

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