Strategies for the Sustainability and Resiliency for the Highway Transportation Infrastructure in Puerto Rico

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Good Morning!
...In solidarity with our Puerto Rican people, in particular those who suffered loss of life and all their property. #PRSeLevanta
Definition of resilience

The ability and capacity of which to absorb disturbances, shocks or impacts while maintaining its capability to function and to reform or recover to its original state.

Resilience is system’s somewhat hidden feature which is revealed only after shock or impact is encountered (Juntunen, 2014).

Below a couple of alternative resilience definitions are given.
Critical components for Resilient Transportation Systems

1. **Robustness:** by improving robustness the transport system will be able to resist shocks and prevent disruptions.

2. **Redundancy:** when redundancy is available a disturbance will be compensated for and the effects on the transport system should be contained.
3. **Resourcefulness**: in case a disturbance does take place, relevant organizations must be prepared and ready to respond and deploy necessary resources to take action.

4. **Rapidity**: having considered different potential scenarios the system can quickly respond and recover. Easy to replace parts/modules/assets, predefined deviation routes are all good examples.
## Critical components for Resilient Transportation Systems (cont.)

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The Challenge

• Transport is vital to well-functioning economies.
• The physical infrastructure is needed to accommodate this.
• The most common types of transport infrastructure: roads, railroads and ports (dry ports, seaports/ waterways and airports).
• These are the hard physical infrastructure components of wider transport systems that include soft infrastructure like policies and regulations, and the institutions responsible for planning, financing, operating and maintaining these systems.
The Challenge (cont.)

• All these components are interconnected into transport systems.

• As societies change, economies grow and new markets emerge, these systems, at least in theory, need to be regularly upgraded in order to remain “fit for purpose”.

• However, when sudden events take place – a major technical failure, serious accident, floods or earthquake – unless these systems have in-built resilience, they can be seriously disrupted.

• The growing degree of the interdependencies of the hard and soft infrastructure components can increase the vulnerability of such systems, making these disruptions more serious, longer lasting and potentially debilitating with serious impacts across economic sectors.
The Challenge (cont.)

Transport systems have become more vulnerable to disasters by the mere fact that they spread across a wider geographical area and more sectors.

No common framework for resilience of transport systems is readily available.
1. Robustness Define

Robustness is the capacity to withstand shocks without losing functionality.

The status of assets plays a role in this. Through wear and tear or maintenance shortcomings (e.g. rust, cracks in concrete) the assets will gradually lose some of the initial capability to withstand shocks.

Capacity to withstand climatologic variations is captured in the original design of assets, but exposure could have changed over time (e.g. excessive rainfall flooding roads, extreme heat jamming a bridge blocking it from opening; and these events becoming more and more frequent)
1. Robustness (cont.)
Physical and Geographical Interdependency

The physical interdependence means the robustness is dependent on other components of these systems (e.g. water pumps keep tunnels dry but are dependent on electricity, sensors and data communication).

Geographical interdependency relates to robustness to shocks along the whole system with down and upstream linkages (e.g. for a waterway a failure of a lock disrupts traffic in an entire river – up and down stream).
1. Robustness (cont.)
Logistical interdependency and Redundancy

Logistical interdependency relates to robustness in term of dependencies, which are not physical or geographical (e.g. the ability of personnel that operates assets and networks to go to during extreme weather events)
2. Redundancy

Redundancy with regards to local workarounds leads to the question whether infrastructure networks have alternative routes available: e.g. goods being able to be taken to destination by roads or railways.
3. Resourcefulness

In the event that natural disasters do disrupt transport, a resilient transport system has the ability to restore functionality, e.g. repairs, to bounce back. Funding, contingency or emergency, is needed to pay for the costs and should be readily available to keep downtime low. Expertise and manpower are needed as well.

But when natural disasters disrupt the systems it can be hard to get the right personnel in the right place at the right time especially when competing demand of the personnel is high. Being prepared for this is crucial to resilience.
4. Rapidity

When infrastructure is resilient, that is, designed and operated in a way that can quickly be restored after lost functionality, disruption effects will be limited. By using systems, assets and parts that are easy to replace, teams are trained and skilled in emergency response and scenarios are thought-through, restoration time can be significantly reduced.

Changing conditions due to climate change provide an extra challenge to keep operation service at required levels.
Transport systems can find generic guidance

• Reducing the impact of the disaster

• Reducing the duration of the disruption

• Balancing spending of resources to improve resilience.
Reliability and resilience can be understood to be almost synonymous

In international contexts, resilience is already widely adopted to reflect the ability of systems to withstand shocks and maintain their capabilities.

Also the ability to recover quickly from shocks is associated as an attribute to resilience (see e.g. European Environment Agency, 2014).

Finland resilience is commonly used in connection with national security of supply and protecting critical infrastructures (Juntunen, 2014).
Transportation and Demographic Characteristics of Puerto Rico

**Land Area:** 9,104 km² (3,515 mi²)

**Population (July 2017):** 3,337,177

**Density:** 2.95 km/km²

**Coast Line:** 501 km (311 mi)

**Transportation:**
- **Highway Network:** 26,860 km (16,694 mi)
- **Bridges:** 2,343 en total (2018)
- **Airports:** 11 total, 5 directly adjacent to the sea
- **Naval Ports:** 12

“Our highways were already in a delicate state, but the damages that occurred would have happened even if they had been in good condition. [...] We had two category 5 hurricanes, back-to-back. We had never experienced this before in Puerto Rico.”

ENG. CARLOS M. CONTRERAS-APONTE  
SECRETARY OF THE PUERTO RICO  
DEPARTMENT OF TRANSPORTATION AND PUBLIC WORKS
“Hurricane María left us with a palpable lesson, a new construction paradigm... part of our built infrastructure in the Island was not even remotely ready for a hurricane of this magnitude. Constructing the same way, informally, only will lead us to repeat the same construction exercise in innumerous occasions.”

Eng. Pablo Vázquez-Ruíz
President CIAPR 2017-2019

Source: El Nuevo Día
“As a nation, we spend hundreds of billions of dollars fixing things after the disaster, in response and recovery, but only a small percentage in strengthening (structures) for future storms. We are doing it the other way around.”

Bryan Koon
Ex-director de Manejo de Emergencias de Florida

Source: El Nuevo Día
"Over the past month, four major Atlantic hurricanes have swept across the ocean. This year’s hurricane season is already the most violent on record, and it will continue until the end of November.

The season fits a pattern: changes to our climate are making extreme weather events more severe and frequent, pushing communities into a vicious cycle of shock and recovery.”

António Guterres
Secretary-General, United Nations

Source: https://www.caribbeanintelligence.com/
PART 1: Hurricane Maria, its Damage, Status and Challenges to Puerto Rico Transportation Infrastructure

PART 2: Strategies for the Sustainability and Resiliency for the Highway Transportation Infrastructure in Puerto Rico
Part 1: Hurricane Maria, its Damage, Status and Challenges to Puerto Rico Transportation Infrastructure
Status of Signalized Intersections

- 1,224 signalized intersections
- 100% of intersections sustained damage
- 600 powered and operational
- 200 intersections remain with severe damage.
- 424 repaired, but not operational
- Traffic Signal Control Cabinet manufacturers

Source: El Nuevo Día

Thursday, March 1, 2018
Status of Repair of Signalized Intersections Critical Component: Traffic Signal Control Cabinet
Challenges with Temporary Traffic Control (TTC) in a Post-Hurricane Setting

Inoperative traffic signals → police and access management for traffic control

Bridge failures, landslides and debris obstruct or destroy highway segments

- Barriers, channelizing devices and signage to block/restrict passage are essential

Source: http://bahiia.com

Source: http://www.utuadohoy.com
Effect of Hurricane María on the Bridge Inventory

- Bridge Inventory: 2,343 (2017):
  - 1,772 over water bodies (75.6%), 571 over highways and other depressions (24.4%)
- Collapsed bridges: **26 (1.1%)**
- Collapsed bridge approaches (bridge closure): **31 (1.3%)**
- Other damages: **331 (14%)**
- Total number of damaged bridges: **388 (17%)**
  - National Highway System bridges with damage: **42 (1.8%)**
- Average year of construction of collapsed bridges: **1968**
- (Average age: 50 years)

Adapted from: IMPACT OF HURRICANE MARIA ON THE PR BRIDGE INVENTORY: HOW TO MOVE FORWARD AND THE IMPORTANCE OF ASSET MANAGEMENT IN THE REBUILDING PROCESS (H. Laureano, MVC 2018)
Representative Bridge related Failures

PR-52 in JUANA DÍAZ, PUERTO RICO
Source: El Nuevo Día

PR-957 in CANÓVANAS, PUERTO RICO
Source: www.miamiherald.com

PR-6632 in CIALES, PUERTO RICO
Source: CBS News

PR-2 in TOA ALTA, PUERTO RICO
Source: Vox News
Failures in the Guajataca Dam Spillway

Source: El Nuevo Día

Source: atodomomento.com

Source: El Comercio
Full Recovery is estimated to be completed by 2019
Estimated Number: 50,000

Fuente: https://landslides.usgs.gov/
Landslides

OROCOVIS, PUERTO RICO
Source: Univision Noticias

COROZAL, PUERTO RICO
Source: Getty Images, Univision Noticias
Coastal Flooding and Erosion

MAYAGÜEZ, PUERTO RICO
Source: Authors

PR-64 in MAYAGÜEZ, PUERTO RICO
Source: Authors
Urban Flooding

GURABO, PUERTO RICO
Source: gfrmedia.com

SAN JUAN, PUERTO RICO
Source: Getty Images, Univision Noticias
River Flooding

PR-2 in YAUCO, PUERTO RICO
Source: Carlos García Rawlings, REUTERS, Univision

GUAYAMA, PUERTO RICO
Source: Carlos García Rawlings, REUTERS, Univision
Destruction of Roadside Appurtenances

YABUCOA, PUERTO RICO
Source: Carlos García Rawlings, REUTERS

TOA BAJA, PUERTO RICO
Source: www.wapa.tv

PR-3 in LUQUILLO, PUERTO RICO
Source: Getty Images, Univision

BAYAMÓN, PUERTO RICO
Source: Authors

May 3, 2019
COLLEGE OF ENGINEERS AND SURVEYORS OF PUERTO RICO
Supply Chain Logistics Break-Down

Line at Service Station, COROZAL
Source: El Nuevo Día

Cashing line at ATM, SAN JUAN
Source: El Nuevo Día

National Guard delivers relief supplies, SALINAS
Source: Diario Libre
Part 2: Strategies for Sustainable and Resilient Transportation Infrastructure

- Coastal Erosion
- Landslides
- Washed-out Pavements
- Traffic Signals
- Debris clean-up
- Power Grid Reconstruction
- Reconstruction of Telecommunications
1. Use of Resilient TTC Equipment

Solar-powered ITS equipment
Retroreflective elements
Provisional intersection control systems

Benefits
- Minimize dependency on external energy supply
- Reduce exposure of traffic control staff
- Ensures nighttime availability, especially when power outages occur

Flexible-but-judicious use can save lives!

Source: http://www.roadsafetraffic.com
Source: https://www.3m.com
Source: http://www.bethsbarricades.com
2. Rigorously enforce laws and regulations in maritime terrestrial zone

- Revise standard drawings of bridge and pavement infrastructure adjacent to coastal areas
- Analyze feasibility of applying hard engineering, green engineering and/or planned relocation for protection of critical assets
3. Review design details of Bridge Abutments

The design of bridge abutments requires further review where high speed and turbulent flow are expected in their design life and potential scouring may occur.
4. Benching for Stability of Roadside Slopes to Minimize Landslide Impact

- Standard Drawings of PRHTA associated with the cut slope sections with clay soils and/or unstable soil rock formation needs to be revisited.

- Use of benching in cut sections with the appropriate slopes needs to be incorporated in future designs.

Source: Authors (above), Panoramio.com (below)
5. Application of Shotcrete Technology to Stabilize of Roadside Slopes

- Mesh to contain rock falls in areas where recurrent falls occurred, needs to be reevaluated.

- Shotcrete in cut sections in highways can be further evaluated to be implemented in the central mountain range as a potential alternate cost-effective design.

Source: http://bestsupportunderground.com
6. Upgrade Shoulders in Major Highway Corridors

- Shoulders in major highway corridors with cut section in mountains with moderate height (less than 800 feet) minimizes the impact of mud and rock slides, thus allowing roadway reconfiguration with at least one lane open to traffic on both directions.

- Shoulders can also accommodate queueing for essential services while minimizing adverse congestion impacts.

Source: https://upload.wikimedia.org
7. Preventive maintenance of urban drainage systems to minimize the potential of flooding

Source: Authors

Source: https://www.montgomerycountymd.gov
8. Development of Strategic Emergency Corridors Maps

The importance of strategic redundancy of principal highway transportation corridors was evident for the mobility of people and goods during the emergency post hurricane María.

Careful planning of redundant routes should take into consideration both traffic volumes and freight, in order to facilitate both emergency response and recovery.

Source: Puerto Rico Highway and Transportation Authority
9. Improvement in Catenary Design and Traffic Signal Supports

The catenary design used in intersections to mount traffic signals needs to be revisited.

The consideration of mast poles to replace catenary designs is pertinent in category 3 and above hurricane alley such as Greater Antilles that include Puerto Rico.

Review design codes for mast poles in the state of Florida, USA after the pass of hurricane Andrew in 1991.
9. Improvement in Catenary Design and Traffic Signal Supports (cont.)

Freeway overhead and roadside guide/directional signs, according to MUTCD with breakaway device in the base that yields on impact, needs to be revisited.

PR-2 km 126.6, AGUADILLA, PUERTO RICO
Source: Authors

BAYAMÓN, PUERTO RICO
Source: Authors
10. Review of Utility and Luminaire Poles Design

- Utility and luminaire poles of all materials (concrete, wood and steel) that failed in the base and the upper 1/3 of their length need to be evaluated for strength against wind loads.

- Vegetation control along utility line corridors is essential to minimize the chance of collapse of entire rows.

Source: https://images-cdn.wapa.tv
Puerto Rico’s government has been creating Strategic Emergency Management Plans for upcoming natural disasters and catastrophes.
Thank you for the opportunity to participate in the 1st COI²NAR/UPADI - 2019