Planning for Cost-Effective Resilience and Adaptation - US Examples

MOWE-IT
MANAGEMENT OF WEATHER EVENTS IN THE TRANSPORT SYSTEMS

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Dealing with extremes of temperatures, rain, wind and flooding will require:

- Attention to hundreds of maintenance & operations details
- Operators and managers applying learning from other (and others’) weather disasters
- Prioritizing hard adaptation investments
Mobility and rapid recovery can be the difference between catastrophe and not.

Dealing with extremes of temperatures, rain, wind and flooding will require:

- Physical resilience to extreme weather enhanced wherever/to the max extent possible
- Ensuring processes and procedures to restore services and routes to normal as quickly as possible
- Clear and effective communication as a supplementary and its own mission
## Impacts and Key Risks Driven by Extreme Heat and Precipitation Events

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What Is Critical?

• Critical = services and assets that are essential to transporting LA Metro’s customers
• i.e., “If this service or asset were removed from the transit system, would the transit system be fundamentally different?”
• Focuses on the services and transit assets affected by such services owned
Planning and Structural Strategies

- Climate integration in *siting and alignment* alternatives decisions
- Infrastructure considerations in *stations*
  - Floodplain analysis
  - Creative solutions resulting from needs
  - Increased pumping capacity
  - Bus stop options at regularly flooded locations
- Low Impact Development: State/Local Requirements
- Use of micro-scaled climate data
- Coordinated emergency response drills
- Practical solutions to identified needs
Creative Solutions to Existing Needs
Operational Strategies

- Pre-emptive maintenance or inspection
  - Bus and Rail Assets and Facilities
- Weather/climate-related monitoring and alerts
- Operational design criteria, e.g., materials up to 120°F
- Energy efficiency and off-peak activities planning
Tools

- GIS Mapping
- Standard Operating Procedures
- Asset database with prioritization criteria
- Cost Analysis and Reinvestments
- Operations Performance Reports
- EMS/EIMS/M3
  - Monitoring and Measurement
  - Task Closeout
- EMS Administrative and Core Teams
Future Work

• Vulnerable populations analysis
• More robust asset management system
• A process of continual improvement
  • Implement and monitor performance metrics
• Highway/transit vulnerability assessment
• Emergency response nexus
• Resiliency demonstrations
  • Documents and document control
  • Infrastructure
  • Energy management

Cris Liban, D.Env., P.E., LibanE@metro.net
Blackout in Manhattan complicated service restoration
Sandy caused catastrophic damage across the system

8 subway stations with major flood damage – South Ferry, Whitehall, 148th St, 207th St, Dyckman, Beach 116th Station, 86th St Sea Beach, Stillwell

Flooded tunnels/tubes
- 9 subway tubes
- Queens-Midtown and Hugh L Carey vehicular tunnels
- 2 of Amtrak’s east river tunnels used by LIRR flooded

Train yards and bus depots with significant flood damage

Staten Island Railway maintenance shop major flood damage

Rockaways track washout

Flooded tunnels/tubes

• Flooded East river tunnels
• Flooded West Side yard
• Extensive power/comm/signal damage

Metro-North Railroad

• 50% of Hudson line submerged
• Harmon yard flooded
• Extensive power/comm/signal damage

MTA Bridges and Tunnels

• Flooding of Hugh L Carey Tunnel
• Flooding of Queens Mid-town tunnel
• Destruction of Marine Parkway and Cross Bay Bridge seawalls
NYCT learned several lessons from Sandy

**Operations**

- Need to ensure business continuity capabilities:
  - Administrative functions/offices
  - Employee emergency communications
- Emergency management improvement opportunities
  - Incident command center
- Partial blackout poses particular challenges for operations

**Infrastructure**

- Traditional vertical barricades (plywood) not robust enough to resist surge-carried debris
- Multiple small bore water ingress points can be very damaging
- Relatively rapid temporary recovery is possible following tube flooding but permanent repairs very challenging
- Powering down all traction power ahead of surge is critical
The Incident Command Center (ICC) was substantially improved in response to needs identified during Sandy.
A large resiliency program with 3 elements is underway

- Water exclusion
- Water ejection and asset protection
- Resilient systems and processes
Detailed surveying of vulnerabilities has been undertaken.
Multiple types of water ingress vulnerabilities exist. MTA NYC Transit has allocated nearly $90 million toward raising ventilation grates and installing stair pads at subway entrances.
Deployable stair covers

Water exclusion
Mechanical closure device developed for vents

Panels Stored Upright

Panels Closed

Water exclusion
A near term temporary solution is being pursued for Coney Island Yard
Increased pumping capacity and secondary protection of critical assets is underway

New pump car online October 2013

• Signal equipment relocated in designs for Montague and Greenpoint tubes to be in less vulnerable locations

• Sealing duct entry points into substations as well as communications and electrical rooms

• Secondary signal and communication room strategies considered for South Ferry design
Critical equipment is being relocated to points of higher elevation during tube recovery projects.

Original equipment location

New location after Recovery project

Water ejection and asset protection
Still working on…

- Investments in higher capacity forecasting
- Developing closer liaison between weather forecasters and transport operators so that during changing weather:
  - There is a shared understanding of the trigger points at which transport operators will need to take managerial decisions about the operation of their service
  - Enabling forecasts to be more closely tailored to those hazards and locations relevant to individual operators
  - Enabling forecasters to understand the optimum timing of warnings to enable transport operators and users to make the appropriate response
Adaptation & Operations
FHWA Efforts

Goal: Develop resources and guidance materials for operating agencies to better prepare for the impacts of climate change and extreme weather on transportation management, operations and maintenance

1. Scope the Issue (2012)

Report: Planning for System Management & Operations as Part of Climate Change Adaptation


Report: Climate-sensitive Decision-making for Operations and Maintenance and the Gaps in Information


Deployment Toolkit for Operating Agencies
Improved cost-benefit analysis/rationale for investment

• Economic and social costs of disruption
  – Insurance industry noted that business continuity costs were their biggest liability in Sandy
  – WSDOT analysis of flooding on I-5, just freight and tax impacts were $75 million

• Costs of rectifying damage caused by extreme weather
  – Estimating as an input to both mitigation and adaptation planning

• Cost-benefit analysis approach, travel time savings, drives most transport investment decision making
  – CDOT flooding analysis vs. FHWA Emergency Relief policies
  – Road Directorates’ Blue Spot Analysis
Identifying, funding, and doing what is critical

• Critical network for strengthening, decision support systems for deciding

• Funding (and providing the rationale for funding) the basic maintenance that reduces risk…
  – Resilience into asset management (pavements – 2014 webinars)
  – Embankments/slopes
  – Culverts/drainage (*Report on Climate Change and Infrastructures and Built/Urban Environments* says special attention should be paid to classes of infrastructure that are toward the end of service lives)

• Contingency plans and practice

• More monitoring and public communication mechanisms (a “good job” is often how well public has been communicated with, to help them make informed decisions. This is a core task.)
Operational challenges

• Agencies may struggle to justify spending on resources and staff that remain unused or underutilized from year to year, and thus be left unprepared for major snow events that occur on a less frequent basis.

• It is unlikely that a once-in-50-years occurrence can be effectively prepared for if once-in-5-years events cannot be handled.
  – Implies that “everyday preparedness” is something that is likely to facilitate preparedness for more extreme events. Otherwise, the learning curves are simply not there.

• This logic puts even more pressure to extreme weather management, where even “low extremes” must be tackled, and hence keeps the preparedness at higher level most of the time. Instead of a special case then, preparation/adaptation should be turned into an almost routine activity.
Transport culvert management systems and risk management with changing storm intensities & frequencies

Photo by Oregon DOT
A few basics on culverts in the US

• A large percentage were installed during construction of the interstate and NHS and are nearing the end of their useful life

• The culvert maintenance backlog is increasing in many states

• The majority of culverts are made of steel

• With regard to management systems: most state DOTs divide culvert inventory monitoring and replacement responsibilities by large and small culverts
Management of large culverts

- **Included in National Bridge Inspection Standards (NBIS):** Bridge/Structures sections tend to have been monitoring large culverts (over 10 ft in diameter since 1970s, sometimes 6 feet), on a 12-24 month frequency, on the NBIS 9-point scale.

- **Replacements Slow and Challenging:** State DOTs are often able to only address a few large culverts (some may become box culverts or small bridges) every year, due to costs.
Management of small culverts

• **Many agencies are still completing their first inventory of small culverts** – usually visual inspections with flashlights

• It took Maryland SHA 10 years to complete theirs

• Ohio DOT started 10 years ago and just found a viable incentive system for completion in the last few years (then just took 2 years)

• Access may inhibit inventory (e.g., Vermont – 70% of small culverts are 24” or less in diameter)
Impetus for Culvert Management Systems or Initiatives

- Unexpected voids
- Extension of state asset management efforts
- NPDES Program requirements
- Risk management
- Accidents, failures, or fatalities

Failed culvert causes road closures in Evansville
Friday, May 10th, 2013, 5:02pm
Utah, State Road 35
7/14/11 11:45 pm
Washout 40 feet wide, sinkhole 35 feet deep swallows 2 cars after heavy rains

• “Justine Barneck, 15, was killed when her father's SUV went over the edge. The sinkhole also caused another car to crash inside the huge depression.”
Crown Inquiry in Australia finds government at fault for failing to maintain culvert – failure led to 5 deaths.
Clarify risk with political decision makers – including what culvert investments are occurring or not, risks

- A Crown Inquiry after a culvert failure in Australia: “CGCC cannot have it both ways. It is either a roads authority or it is not. As a road authority it is expected to conduct itself in a competent and professional manner. The investigation of the collapse of the culvert and road above shows that it did not act so.”

- “There hasn’t been much conversation of who owns the consequences below the line. At the political level, the politicians said they didn’t understand. Asset managers had not transferred (understanding of the implications of what they could not afford to do) to the political level.”
Percentage of undersized culverts rising with precipitation and especially extreme events (three 1000-year events in 5 years in MN) Minneapolis

The 50-year storm (a storm intensity that occurs, on average, every 50 years) is now occurring every 10 years.
Recent conditions

Drainage system adequacy

With population growth

And more extreme rainfall
ERG Duluth MN & Toledo OH
Study Components

- **Climate Prediction**: How much precipitation in 2035? *(EPA’s CREAT Model)*
- **Hydrology and Hydraulics**: What are the resulting flood elevations and associated impacts? *(Corps working with community models e.g., HEC, SWMM, SWAT)*
- **Flood Damage Estimate**: What is the cost of the damage? *(FEMA’s HAZUS Model)*
- **Planning**: What can be done to minimize damages? *(Land Use and Gray-Green Infrastructure Options)*
- **Economics**: What are the costs and benefits of the adaptation options?
How do the models work together?

- **CREAT**
  - Historical climate data
  - Projected climate data

- **H&H**
  - Peak flow
  - Runoff volume
  - Base flood elevation

- **HAZUS**
  - Flood damage costs
Economic elements

• Monetize primary and secondary costs based on HAZUS (property damage) outputs

• Estimate average annualized costs for a set of flooding events at different intensities

• Evaluate difference in cost under the four operating assessment scenarios

• Estimate co-benefits (water quality, recreation, fisheries) of green infrastructure for fuller cost accounting
Key purpose of culvert management systems: timely and efficient repairs

Agencies want to maintain, repair and rehabilitate culverts in a timely way, save money, avoid emergencies & negative publicity

• Avoid and minimize expensive emergency repairs (failed culverts, especially if they are deeply buried, can be expensive, dangerous, and disruptive to repair).

• **Costs:** Maintenance of traffic during repairs is often more expensive than **installation**, which in turn tends to be more expensive than the **materials used**

• **Effective rehab technologies are available.** An asset management plan that addresses problems before failure can **add decades to culvert life and save millions of dollars**
Applies ratings describing aspects of potential failure mechanisms and their consequences, to derive an ARL for each hazard present, and consequently a rating for the culvert.

1. Identify applicable hazard mechanisms
2. Apply likelihood analysis
3. Apply consequence analysis
4. Merge to assign a risk rating
CMS, risk analysis → efficient & effective use of resources + cost savings

- DOTs are finding that inventory and inspection programs for culverts inherently reduce risk.
- Maintenance has found that “knowing locations itself leads to more frequent checking, timely clearing, & avoidance of emergencies.”
Risk management process

- Establish context
- Identify hazards
- Analyse risks
  - Likelihoods
  - Consequences
  - Risk levels
- Evaluate risks
- Treat risks
- Communicate and consult
- Monitor and review
Structural collapse hazard identification

- Potential for void or settlement at road surface due to collapse of culvert barrel.
- Likelihood (L) of void or settlement of road surface.
- Potential propagation of void to road level.
- Collapse of barrel due to deterioration, corrosion of metal culvert.
- Potential buckling (metal culvert).
Transport agencies are working on expanding small culvert management

Lessons learned:

• It’s normal to encounter setbacks
• Collect data you *really* need and will use
• Designing a program for completion in a small number of years can minimize vulnerability to unexpected changes and inventory derailment (Supplement staff if needed with temp or consultants)
• Senior leadership backing and attention, helps a lot. Quantifying benefits helps communicate the need so that it is actionable at higher levels (exec. management, Commission, legislature)
Expanding small culvert management

- ODOT: “There needs to be a funding mechanism that rewards Districts for inventorying and inspecting culverts, a ‘carrot’ method”

- “It takes dedicated staff at Central Office and the Districts to promote and administer the program” – at least one FTE at HQ, with teams/leads in each District to get the job done (construct a working culvert asset management system)

- Risk management is not just a response to extreme weather though:
  - Some (social) values are more extreme than others
  - Some weather is more extreme in intensity and impacts
  - Costs, risks, and preparedness for different extremes differ across states and regions
Applies ratings describing aspects of potential failure mechanisms and their consequences, to derive an ARL for each hazard present, and consequently a rating for the culvert.

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Managing User Delay Cost

Goal: Limit 2013 User Delay Cost to $304.4 Million by 12/31/13

**Winter Weather sub-goal:**
Regain Time < 2 hours 80% of the time

Lead Measure 1:
Perform After Storm Huddles 80% of the time

Lead Measure 2:
Compliance with Salting Policies 80% of the time

**TIM sub-goal:**
Limit the number of traffic incidents closing 1+ lanes lasting longer than 2 hours to 203

Lead Measure 1:
Perform Post Incident Reviews 75% of the time

**Work Zone sub-goal:**
Limit Non-Recurring Construction User Delay Cost to $80.3M

Lead Measure 1:
Perform WZ Reviews 80% of the time

Lead Measure 2:
Compare Predicted vs. Actual Capacity & Diversion Rates
Vehicle Data Sources

SIGNAL
Position - GPS
speed
direction
altitude
distance
vehicle dynamics
(accelerometer)
Roughness (accelerometer - vertical)
photo
VIN
RPM
Throttle Position
Anti-lock Braking System
Traction Control
Barometer
Air temperature
Pavement temperature
Humidity
Dew point
Potential Applications

- Data quality checks (ground truth - RWIS stations & third party speed data)
- Targeted individual messages (augments DMS & website)
- Provide travel times and incident updates
- Performance Measure/Management
- In-the-storm performance (how well are you managing the event)
- Maintenance Decision Support System
- Remote imaging and physical monitoring of environment (camera photos)
- Visibility monitoring (i.e.: snow squalls, localized lake effect white outs, fog, rain)
- Slippery surface notification (ABS lockup & differential wheel speed)
- Pin point icy road conditions (driver & maintenance staff)
- Early notification to First responders, Hospitals, Work place, Schools, Community events, etc.
- Regional and cross jurisdictional alerts (Great Lake Regional Transportation Operations Coalition ties into the Northwest Passage and other regional coalitions)
- Vehicle/device health monitoring (are devices installed on vehicles working?)
- Vehicle diagnostics (fleet monitoring and management (miles, hours, routine maintenance, etc.)
- Provide in-vehicle alerts
Lessons Learned

- Performance Measures w/o Performance Management does not achieve improved system performance
- Process requires full support from top management
- Need automation to help manage the process. Can’t let the process itself overrun other staff daily duties
- Are we measuring the right things? Choosing the right measure (and wording) takes time
- Tracking project performance 24-7 maintains staff focus on mobility and improves decision making toward operations
- User Delay Cost has a relationship to actual contract bid cost. Finding appropriate balance isn’t easy, however, measuring it provides a better end result for motorists
Conclusions

To improve practice and achieve resilience we need to share experience...

• Until disasters/on-the-ground experience (and because of this, local staff are often the most aware of problems), many DOTs are unsure of level of consideration/budget to give to M&O adaptation action.
Protect inter-dependent systems, especially power/controllers:

• Some examples of infrastructure impacts of extreme events:
  The Baltimore tunnel fire of 2001: five days of downtown flooding, 1200 downtown buildings without power, fiber-optic cable destroyed (interrupting Internet service in the NE), transportation systems disrupted
  - The Northeast blackout of 2003: 50 million people lost electric power, widespread shutdowns of water pumping stations and loss of water pressure – causing water contamination, loss of power to oil refineries…

• Some examples of current US regional vulnerabilities:
  - The coastal Northeast, vulnerable to a combination of dense urban-industrial development, increasingly strong coastal storms, and sea-level rise: e.g., the recent experience with Superstorm Sandy (and Irene before)
  - The Gulf Coast, vulnerable to a combination of economic/demographic growth, increasingly strong coastal storms, sea-level rise, and land subsidence: e.g., the experience with Hurricanes Katrina, Rita, Gustav, & Ike – under BAU Katrina/Rita-like storms may occur 2.5x more often in the future
In the most severe of the climate change scenarios, current land uses in some areas, including coastal parts of the NYC metropolitan area may be difficult to sustain.
Atlantic City: Today’s 100-Year Flood Could Become a Two-Year Flood by 2100

The top image shows the location of Atlantic City, NJ, on Absecon Island. The light blue area in the bottom image depicts today’s FEMA 100-year flood zone (which extends beyond the area shown). Currently, this area has a 1 percent chance of being flooded in a given year. By 2100, this approximate area is projected to flood, on average, once every year or two under either emissions scenario, inundating high-tourist-value hotels and casinos. Under the higher-emissions scenario, the new 100-year flood height would be roughly four feet greater in 2100 than today, flooding a far greater area than the current FEMA flood zone.

Landmarks
A. Atlantic City Boardwalk Hall
B. Caesars Atlantic City
C. Bally’s Atlantic City
D. The Boardwalk
E. Trump Taj Mahal
F. Gardner’s Basin
G. Gardner Pier
Locations in New York City Power Plants Relative to 10-foot Elevation Contour
Inter-dependent systems, especially power pose risks with climate change & EWEs

- Extreme weather events associated with climate change will increase disruptions of infrastructure services in some areas.
- Disruptions of services in one infrastructure will almost always result in disruptions in one or more other infrastructures, especially in cities.
- Such linkages will trigger serious cross-sectoral cascading infrastructure system failures in some areas, for days/weeks.
- These risks are greater for infrastructures that are:
  - Located in areas vulnerable to extreme weather events.
  - Located at or near particularly climate-sensitive environmental features, such as coastlines, rivers, storm tracks, etc.
  - Already stressed by age and/or by demand levels over design.
Communications and training costs/needs, flexible allocation

- Integration of sophisticated weather information at transportation operations centers – need training and support on using new tools and interpreting and applying forecasts to make operational decisions.
- Growing capabilities with increased multi-agency coordination and multi-agency emergency operations centers in larger events.
- Budgets with flexible resource allocations to respond to larger and more variable weather events, less regular to the region, and training for such events.
Performance metrics
maintenance of weather-related
disruptions

• How frequently they occur at a certain location or system-wide across a region
• Causes
• Costs (infrastructure, time, etc.) Hours lost
• “Back to normal” time
• Other factors relevant to decision-making; e.g., ability to be prepared for or to avoid problems
Being strategic

- Cost-effectiveness is not the only factor, but it is the language of most investment decisions today – more data collection and estimation of socio-economic costs and benefits are important
- Bundling climate change responses with other development/sustainability issues
- Improved indicators of resilience and rethinking “optimization” in a risk management context
- Addressing issues regarding financing
- Rethinking codes and standards for built infrastructure design, construction, and operation to remove assumptions of stationarity of climatic and other parameters, encourage flexibility as an objective for infrastructure capital stock
- Actively seeking to spur innovation, share learning
Climate resilient pathways for infrastructure adaptation

• Will require design for *flexibility as an objective* along with *selective redundancy* where particular interdependencies threaten cascading system failures in the event of disruptions.

• In some cases, especially if climate change is substantial, climate-resilient pathways will require *transformational changes*, beyond incremental changes – how do we begin to imagine the unimaginable… and promote participative contingency planning for big changes?

• Focal events (such as extreme storms or floods) can create “policy windows” for getting decisions made that are difficult under normal circumstances: the challenge is to be ready when the window opens, before it closes… (i.e., have plans/budget for longer term adaptation during re-building)
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